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Evaluation of Crop Suitability for Reclaimed Tideland Soils Using Soil and Water Salinity and Soil Texture

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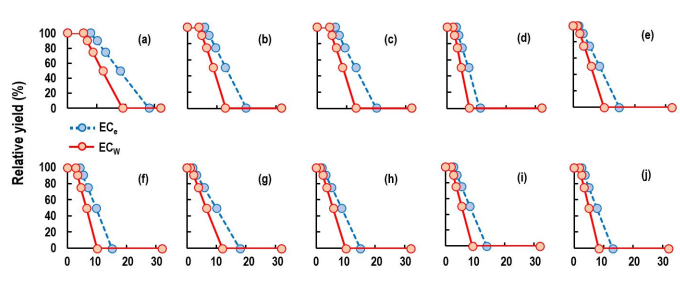
ABSTRACT

There are increasing social pressures on the agricultural use of salt-affected reclaimed tideland (RTL) for the cultivation of other crops except for rice. Crop suitability for RTL has conventionally been evaluated using soil salinity alone without consideration of soil texture and water salinity. In this study, the suitability of 10 crops for 12 RTLs under national government's management was evaluated using soil and water salinity as well as soil texture. The crops include barley (both cereal and forage) (*hordeum vulgare*), wheat (*triticum eastivum*), paddy rice (*oryza sativa*), maize (forage) (*zea mays*), beet (*beta vulgaris*), celery (*apium graveolens*), spinach (*spinacia oleracea*), broccoli (*brassica oleracea* var. italic), and tomato (*solanum lycopersicum*). The results showed that barley and wheat are most suitable winter crops for all RTLs and beet, celery, and maize are more suitable than others as summer crops. The suitability of rice, which is widely cultivated in all RTLs, was not as high as expected in some RTLs, suggesting that it may be possible to consider other crops as alternative summer crops to rice. By using not only soil salinity but also soil texture and water salinity as parameters for crop suitability evaluation, it was possible to recommend suitable crops for each RTL of which soil texture and soil and water salinity differ.

Keywords: Crop cultivation, Land use, Reclaimed tideland, Soil salinity, Water salinity



Yield responses of 10 selected crops to soil (EC_e) and water (EC_w) salinity.

Introduction

In South Korea, reclaimed tidelands (RTLs) have been constructed to create new land for enlarging arable land to ensure food security, and the area of RTLs is estimated to be 186,639 ha, which is equivalent to 11.7% of total arable land and 22.1% of rice cultivating land in 2018 (MOAF, 2019). The RTLs are often located in lowland with high groundwater level and high salinity, which inhibit growth of many upland plants (Lee et al., 2003a; Huang et al., 2008). In RTLs, rice (*Oryza sativa* L.) is commonly cultivated over other crops for two main reasons: firstly, rice is the most important staple food and secondly, rice is cultivated under waterlogged conditions and thus may has less salt stress due to leaching of excessive salt below rooting zone during growing seasons (Abrol et al., 1988; Lim et al., 2020). However, with reduction of rice consumption, there are increasing social pressures on the multi-purposes use of RTLs including production of other cereal and food except for rice (Kang et al., 2019).

Many studies have been conducted to test the suitability of a variety of crop species such as miscellaneous cereals (Kang et al., 2019), vegetables (Lee et al., 2003b), and forage (Shin et al., 2004) for cultivation in RTLs soils with a special consideration of soil salinity. The tested crops include corn (*Zea maize* L.), millet (*Panicum miliaceum* L.), sorghum (*Sorghum bicolor* L.), buckwheat (*Fogopyrun esculentum* L.), and soybean (*Glycine max* L) for miscellaneous cereals (Lee et al., 2003b; Lee et al., 2016; Kang et al., 2019); Chinese cabbage (*Brassica campestris* L.), radish (*Raphnus raphanistrum* L.), tomato (Solanum lycopersicum L.), lettuce (*Lactuca sativa* L.), beet (*Beta vularis* L.) and turnip (*Brassica rapa* L.) for vegetables (Lee et al., 2003b; Jo et al., 2018); sorghum (*Sorghum bicolor* L. Moench.)×sudangrass (*Sorghum sudanense* Piper), Italian ryegrass (*Lolium multifiorum* Lam.), and kenaf (*Hibiscus cannabinus* L.) for forage crops (Shin et al., 2004, 2005; Kang et al., 2018).

However, in salt-affected soils including RTLs in South Korea, not only soil salinity but also water salinity should be considered to evaluate crop growth and suitability in the soils (Eynard et al., 2005; Lim et al., 2020) as water salinity directly affects crop growth and also determines leaching requirement for the growth of a certain crop species to maintain soil salinity below a threshold level (Skaggs et al., 2012; Cucci et al., 2019). For example, even rice, which is widely cultivated in salt-affected soils, is known to be susceptible to water salinity stress; e.g., rice yield decreases when electrical conductivity (EC_w) of irrigation water is > 2 dS m^{-1} and no yield is expected when EC_w is 7.6 dS m^{-1} (Maas and Hoffman, 1977; Lim et al., 2020). In addition, as many upland crop species are sensitive to excess moisture stress and poor aeration, soil textures of the RTLs may be another barrier for cultivation of divergent crop species (Yamauchi et al., 2018).

Therefore, it is highly necessary to take water salinity and soil texture as well as soil salinity into consideration to evaluate the suitability of crop cultivations in RTLs soils. In this study, to provide a comprehensive methodology for selection of crop species suitable for RTLs and to recommend crop species suitable for 12 RTLs under national government's management, the suitability of crop species to the RTLs was evaluated using soil and water salinity and soil texture.

Materials and Methods

RTLs study sites and sampling This study was conducted with 12 RTLs soils under national government's management: Bojeon (BJ), Goheung (GH), Gunnae (GN), Hwaong (HO), Iwon (IW), Nampo (NP), Sihwa (SH), Seokmoon (SM), Saemangeum (SMG), Samsan (SS), Yeongsangang 3-1 (YS 3-1), Yeongsangang 3-2 (YS 3-2)

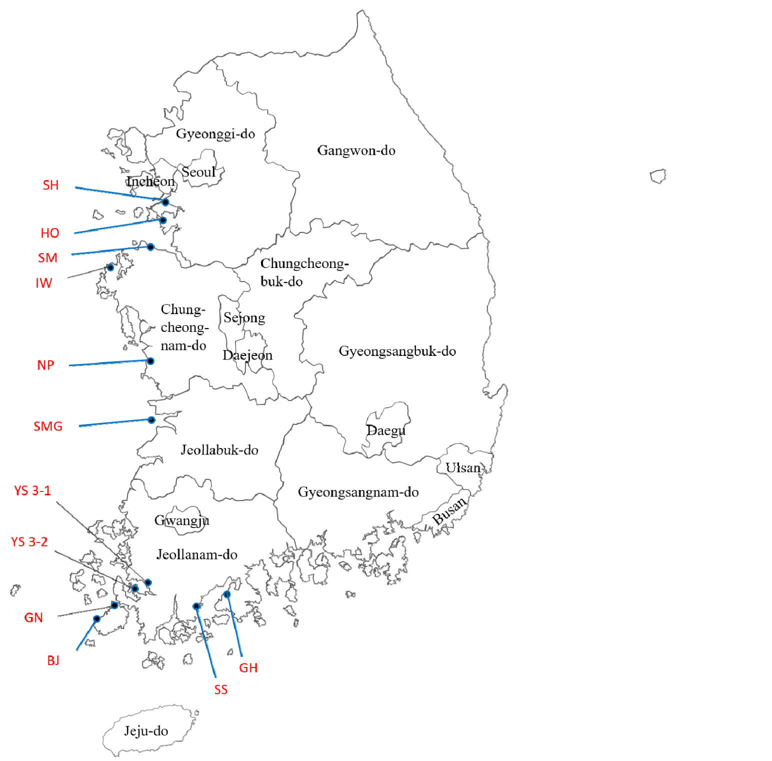


Fig. 1. Locations of the study reclaimed tideland (RTL) (n=12). Information including land area, number of soil sampling, and water sampling locations as well as the code names of the RTLs are provided in Table 1.

Table 1. The location and area of 12 reclaimed tideland (RTL) study site, number of soil sampling, and water sampling location.

RTL	Administrative districts	Area (ha)		Number of soil sampling fields	Water sampling location
		Land	Estuary reservoir		
Bojeon (BJ)	Jindo, Jeonnam	213	85	3	Bojeon seawall
Goheung (GH)	Goheung, Jeonnam	2,213	977	9	Goheung lake
Gunnae (GN)	Jindo, Jeonnam	492	408	7	Gunnae lake
Hwaong (HO)	Hwaseong, Gyeonggi	4,482	1,730	10	Hwaseung lake
Iwon (IW)	Taean, Chungnam	1,199	153	6	Iwon seawall
Nampo (NP)	Boryeong, Chungnam	600	82	5	Nampo seawall
Sihwa (SH)	Ansan, Gyeonggi	3,636	760	7	Sihwa lake, Tando lake
Seokmoon (SM)	Dangjin, Chungnam	2,780	960	6	Seokmoon lake
Saemangeum (SMG)	Gunsan, Jeonbuk	28,300	11,800	6	Gyaehwa port, Simpo port
Samsan (SS)	Jangheung, Jeonnam	280	140	7	Samsan seawall
Yeongsangang 3-1 (YS 3-1)	Youngam, Jeonnam	7,960	4,856	9	Yeongam lake
Yeongsangang 3-2 (YS 3-2)	Haenam, Jeonnam	4,565	2,868	8	Gumho lake

(Table 1 and Fig. 1). In the spring of 2018, surface soil (0 - 20 cm) samples were collected using soil augers from 3 - 10 fields for the RTLs considering the land area of the RTLs (Table 1). Water samples were collected from the estuary reservoir in the RTLs four times in the spring, middle summer (before monsoon season), late summer (after monsoon season), and fall (at harvest) (Table 1).

Analyses of soil and water samples Soil samples were air-dried, passed through a 2-mm sieve, and used for analyses. Particle size distribution was determined using the pipette method (Gee and Bauder, 1986). For measurement of electrical conductivity of saturated soil paste (EC_e), approximately 500 g of soil samples were placed into a plastic container, and distilled water was added until the soils reached a condition of complete saturation as described in the USDA Handbook 60 (US Salinity Laboratory Staff, 1954; Park et al., 2019). The extracts of saturated pastes were obtained under vacuum using a vacuum extractor (SampleTek 24VE, MAVCO INDUSTREIS, Inc., Kentucky, USA), and EC was measured using a conductivity meter (Orion 3 STAR, Thermo Fisher Scientific Korea, Seoul, Korea). Water samples were also analyzed for EC_w using the conductivity meter.

Evaluation of the crop suitability Initially, we tested a total of 29 crop species, and the 10 crop species were selected with the consideration of the threshold soil and water salinity and soil texture suitability of crop growth in RTLs. Suitability of crop species to RTLs was evaluated through a scoring procedure (Table 2) using soil texture

Table 2. Scoring procedure for the evaluation of crop suitability to reclaimed tideland soils using soil texture and soil and water salinity.

Parameter	Perfect score	Scoring method	Reference
Soil texture	20	20, if suitable 0, if not suitable	NAS (2017)
Soil salinity	40	Scoring using the relationship between relative yield (Y_r) of a specific crop and EC_e, $Y_r = A - EC_e \times f$, where A is y-intercept and f is a crop yield reduction coefficient (Fig. 2 and Table 5). The equation was derived from the yield changes with EC_e of Food and Agriculture Organization (Table 4). When EC_e is the same as or below the threshold EC_e, Y_r becomes 100 and a perfect score (40) is given to soil salinity score. When EC_e is above the threshold EC_e, Y_r (<100) is obtained from the equation and the salinity score is computed as $40 \times (Y_r/100)$; and if Y_r is negative, zero is given to the soil salinity score.	Abrol et al. (1988)
Water salinity	40	Scoring using the relationship between relative yield (Y_r) of a specific crop and EC_w, $Y_r = A - EC_w \times f$, where A is y-intercept and f is a crop yield reduction coefficient (Fig. 2 and Table 5). The equation was derived from the yield changes with EC_w of Food and Agriculture Organization (Table 4). When EC_w is the same as or below the threshold EC_w, Y_r becomes 100 and a perfect score (40) is given to water salinity score. When EC_w is above the threshold EC_w, Y_r (<100) is obtained from the equation and the salinity score is computed as $40 \times (Y_r/100)$; and if Y_r is negative, zero is given to the water salinity score.	Abrol et al. (1988)
Total	100	The sum of the scores of soil texture, soil salinity, and water salinity.	

and soil and water salinity as parameters. Perfect scores for soil texture (20) and soil (40) and water (40) salinity were set to be the total sum is 100. The perfect scores (each 40) were allocated arbitrarily to soil and water salinity first considering the well-established data base of the effects of soil and water salinity on crop growth (Ayers and Westco, 1985; Abrol et al., 1988), and the remainder (20) was allocated to soil texture. The score allocation can be varied depending on the opinion of researchers; however, as the scoring compares relative suitability ranking amongst various crops, the results should not be different with the score allocation method in a certain RTL.

For soil texture score, proper soil texture group for cultivation of crop species provided by NAS (2017) was used (Table 3); specifically, if the soil texture of a RTL is within the texture group, 20 was given and if soil texture is out of the texture group, the RTL was scored 0. For soil salinity score, the database of Food and Agriculture Organization on yield changes with EC_e (Table 4, Abrol et al., 1988) was used. Using the database, the relationship between relative yield (Y_r) of a specific crop and EC_e (Table 4), an equation, $Y_r = A - EC_e \times f$, where A is y-intercept

Table 3. Soil texture group suitable for cultivation of the selected 10 crops.

Crops		Suitable soil texture groups
Common name	Academic name	
Barley	*Hordeum vulgare*	Sandy loam, loam, and silt loam
Barley (Forage)	*Hordeum vulgare*	Sandy loam, loam, and silt loam
Wheat	*Triticum eastivum*	Sandy loam, loam, and silt loam
Paddy rice	*Oryza sativa*	Sandy loam, loam, clay loam, silt loam, and silty clay loam
Maize (Forage)	*Zea mays*	Sandy loam, sandy clay loam, loam, clay loam, silt loam, and silty clay loam
Beet	*Beta vulgaris*	Sandy loam, loam, and clay loam
Celery	*Apium graveolens*	Sandy loam, loam, and clay loam
Spinach	*Spinacia oleracea*	Sandy loam, loam, and clay loam
Broccoli	*Brassica oleracea var. italica*	Sandy loam, loam, and clay loam
Tomato	*Solanum lycopersicum*	Silty clay loam

Table 4. Soil (EC_e) and water (EC_w) salinity at a certain relative yield of crop species: example of the selected 10 crops.

Crops	Relative yield (%)									
	100		90		75		50		0	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Barley	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28.0	19.0
Barley (Forage)	6.0	4.0	7.4	4.9	9.5	6.4	13.0	8.7	20.0	13.0
Wheat	6.0	4.0	7.4	4.9	9.5	6.3	13.0	8.7	20.0	13.0
Paddy rice	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11.0	7.6
Maize (Forage)	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15.0	10.0
Beet	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15.0	10.0
Celery	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18.0	12.0
Spinach	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15.0	10.0
Broccoli	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14.0	9.1
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13.0	8.4

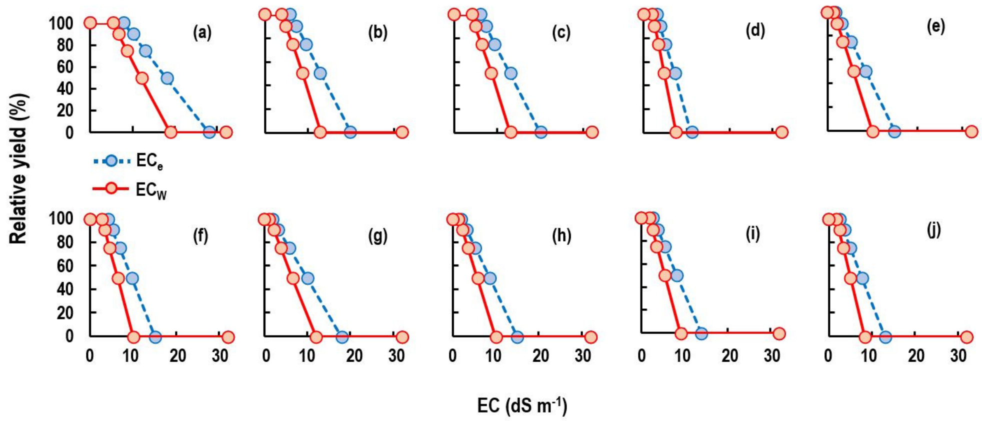


Fig. 2. Change in relative yield of crop species with soil (EC_e) and water (EC_w) salinity: examples with 10 selected crops; (a) barley, (b) barley (forage), (c) wheat, (d) paddy rice, (e) maize (forage), (f) beet, (g) celery, (h) spinach, (i) broccoli, and (j) tomato. Data from Abrol et al. Lee(1998).

Table 5. Regression equations for the relationship of relative yields (Y_r) of the selected 10 crops with soil (EC_e) and water (EC_w) salinity (x variables) using the data in Table 4.

Crops	EC_e †	EC_w †
Barley	$Y_r = -5.0x + 140$	$Y_r = -7.3x + 138.7$
Barley (Forage)	$Y_r = -7.1x + 142.9$	$Y_r = -11.1x + 145.1$
Wheat	$Y_r = -7.1x + 142.9$	$Y_r = -11.1x + 144.7$
Paddy rice	$Y_r = -12.5x + 138$	$Y_r = -17.9x + 136.1$
Maize (Forage)	$Y_r = -7.6x + 114.3$	$Y_r = -11.4x + 114.2$
Beet	$Y_r = -9.1x + 136.6$	$Y_r = -13.6x + 136.7$
Celery	$Y_r = -6.2x + 111$	$Y_r = -9.3x + 111.2$
Spinach	$Y_r = -7.7x + 115.6$	$Y_r = -11.5x + 115.2$
Broccoli	$Y_r = -8.9x + 124.5$	$Y_r = -13.9x + 126.3$
Tomato	$Y_r = -9.5x + 123.1$	$Y_r = -14.9x + 124.9$

Relevant regression analyses are shown in Fig. 2.
† Application of the equations are described in Table 2.

and *f* is a crop yield reduction coefficient, was developed for each crop (Fig. 2 and Table 5). When EC_e is the same as or below the threshold EC_e, Y_r was assumed to be 100 that is equivalent to the perfect score (40) for soil salinity; and when EC_e is above the threshold EC_e, Y_r (<100) is obtained from the equation and the salinity score is computed as $40\times(Y_r/100)$. Water salinity score was developed as the same as the soil salinity score. Total suitability score was calculated as the sum of the scores of soil texture, soil salinity, and water salinity.

Results and Discussion

Soil texture and soil and water salinity Soil particle size distribution varied largely within a RTL and across 12 RTLs soils (Fig. 3). For example, the mean % sand varied from 8.5% for GN to 82.4% for SMG, and among the

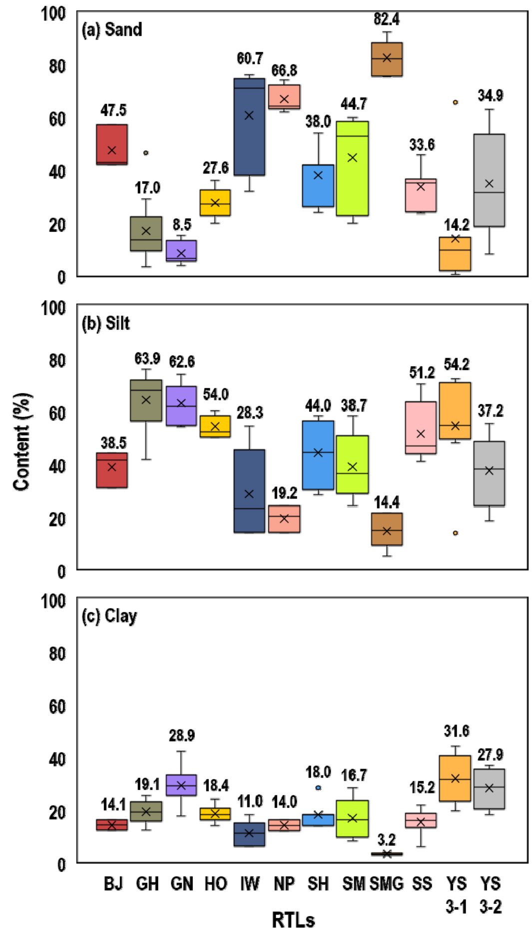


Fig. 3. Box plots of the distribution of (a) sand, (b) silt, and (c) clay of the reclaimed tideland (RTL) soils. Average values are depicted for each RTL. Boxes represent interquartile ranges (IQRs) and horizontal lines within boxes indicate median values. The upper and lower whiskers indicate 75 percentile plus 1.5 IQR and 25 percentile minus 1.5 IQR, respectively. × is average value, and ○ is a mild outlier of which value > 75 percentile plus 1.5 IQR, but <75 percentile plus 3.0 IQR.

12 RTLs, IW, NP, and SMG RTLs had greater % sand than the others. The % clay varied within a narrow range from 3.2 to 31.6%. The representative soil texture determined with the average % clay, silt, and sand was loam for BJ, silt loam for GH, silty clay loam for GN, silt loam for HO, sandy loam for IW and NP, loam for SH and SM, sandy loam for SMG, silt loam for SS, silty clay loam for YS 3-1, and clay for YS 3-2 (Table 6).

The average EC_e ranged widely from 1.2 dS m^{-1} for GH to 12.5 dS m^{-1} for SS (Fig. 4a). Soil salinity is classified into six categories based on the impacts of crop yield; non saline (EC_e 0 - 2 dS m^{-1}, salinity effect is negligible), slightly saline (EC_e 2 - 4 dS m^{-1}, yields of sensitive crops may be restricted), moderately saline (EC_e 4 - 8 dS m^{-1}, yields of many crops are restricted), strongly saline (EC_e 8 - 16 dS m^{-1}, only tolerant crops yield satisfactorily), and very strongly saline (EC_e >16 dS m^{-1}, only a few very tolerant crops yield satisfactorily) (Abrol et al., 1988; Francois and Maas, 1999). Therefore, according to the classification, GH is non saline, NP, SH, and SMG are slightly saline, and BJ, HO, IW, SM, and YS 3-2 are moderately saline, and GN, SS, and YS 3-1 are strongly saline.

The average EC_w ranged from 1.1 dS m^{-1} for SS to 36.0 dS m^{-1} for SH (Fig. 4b). Irrigation water quality is evaluated with many parameters including EC_w, sodium adsorption ratio, and specific ions concentration such as Na, Cl, and B (Ayers and Westcot, 1985). Based on EC_w, the degrees of the restriction on use of the water can be classified into three categories; none restriction for EC_w <0.7 dS m^{-1}, slight to moderate degree for EC_w 0.7 - 3.0 dS

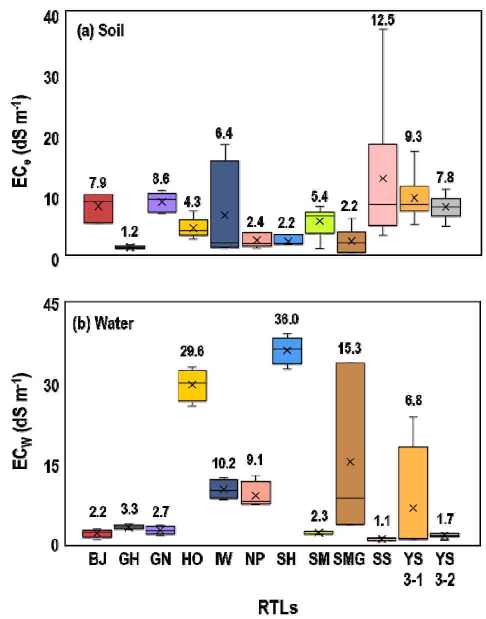


Fig. 4. Box plots of the distribution of (a) soil salinity (EC_e) and (b) water salinity (EC_W) of the reclaimed tideland (RTL) soils. Average values are depicted for each RTL. Boxes represent interquartile ranges (IQRs) and horizontal lines within boxes indicate median values. The upper and lower whiskers indicate 7 percentile plus 1.5 IQR and 25 percentile minus 1.5 IQR, respectively. × is average value.

Table 6. Summary of soil texture and mean soil (EC_e) and water (EC_W) salinity of the 12 reclaimed tideland soils.

RTL	Soil texture†		Salinity (dS m^{-1})	
	Group (% of distribution)	Representative‡	EC_e	EC_w
Bojeon (BJ)	L (67), SL (33)	L	7.9	2.2
Goheung (GH)	SiL (67), C (22), L (11)	SiL	1.2	3.3
Gunnae (GN)	SiL (43), SiCL (43), SiC (13)	SiCL	8.6	2.7
Hwaong (HO)	SiL (100)	SiL	4.3	29.6
Iwon (IW)	SL (67), SiL (17), L (16)	SL	6.4	10.2
Nampo (NP)	SL (100)	SL	2.4	9.1
Sihwa (SH)	SiL (43), L (29), CL (14), SL (14)	L	2.2	36.0
Seokmoon (SM)	SL (50), SiL (17), CL (17), L (16)	L	5.4	2.3
Saemangeum (SMG)	LS (83), S (17)	SL	2.2	15.3
Samsan (SS)	L (71), SiL (29)	SiL	12.5	1.1
Yeongsangang 3-1 (YS 3-1)	SiCL (44), SiL (22), SiC (22), SCL (12)	SiCL	9.3	6.8
Yeongsangang 3-2 (YS 3-2)	SiCL (25), CL (25), L (25), SCL (13), SL (12)	C	7.8	1.7

†C, Clay; SiC, Silty clay; SiCL, Silty clay loam; SiL, Silt loam; CL, Clay loam; L, Loam; SCL, Sandy clay loam; SL, Sandy loam; LS, Loamy sand; S, Sand.

‡Representative texture was determined with the average % distribution of clay, silt, and sand of the RTL soils.

m^{-1}, and severe degree for EC_w >3.0 dS m^{-1} (Ayers and Westcot, 1985). Therefore, according to the classification, agricultural water in BJ, GN, SM, SS, and YS 3-2 can be used for irrigation with slight to moderate restriction; whereas for the others, severe restriction is required. Taken soil and water salinity together (Table 6), GH is expected to be more suitable for crop growth than other RTLs, and soil salinity may be the limiting factor for crop growth in BJ, GN, SM, SS, and YS 3-2, whereas water salinity for NP, SH, and SMG and both soil and water salinity for HO, IW, and YS 3-1.

Crop suitability By using not only soil salinity, but also soil texture and water salinity as scoring parameters, it was possible to make sophisticated score being different among crop species. For example, in GH, all the crops had perfect score (40) for soil salinity, but scores for soil texture and water salinity differed, resulting in different total score (Table 7). If soil salinity was used as single parameters, therefore, it would result in the same suitability score for the 10 crops. Overall, among the 12 RTLs, BJ, GH, and SM had relatively higher suitability score than others due to lower EC_w (for BJ and SM) or lower EC_e (for GH); whereas HO and SM, which had higher EC_w as well as YS 3-1 with moderate EC_e and EC_w but finer texture (silty clay loam) showed the lower score compared to other

Table 7. Ranking of crop suitability score for cultivation in 12 reclaimed tideland soils using soil texture and soil and water salinity.

Ranks	Reclaimed tidelands[†]											
	BJ	GH	GN	HO	IW	NP	SH	SM	SMG	SS	YS 3-1	YS 3-2
1	Ba (100)[‡] (20/40/40)[§]	Ba (100) (20/40/40)	Ba (79) (0/39/40)	Ba (60) (20/40/0)	Ba (86) (20/40/26)	Ba (89) (20/40/29)	Ba (60) (20/40/0)	Ba (100) (20/40/40)	Ba (71) (20/40/11)	Ba (91) (20/31/40)	Ba (73) (0/37/36)	Ba (80) (0/40/40)
2	Bf (95) (20/35/40)	Bf (100) (20/40/40)	Bf (73) (0/33/40)	Bf (60) (20/40/0)	Bf (72) (20/39/13)	Bf (78) (20/40/18)	Be (60) (20/40/0)	Bf (100) (20/40/40)	Be (60) (20/40/0)	Bf (82) (20/22/40)	Bf (59) (0/31/28)	Bf (75) (0/35/40)
3	W (95) (20/35/40)	W (100) (20/40/40)	M (73) (20/20/33)	W (60) (20/40/0)	W (72) (20/39/13)	W (77) (20/40/17)	Bf (60) (20/40/0)	W (100) (20/40/40)	Bf (60) (20/40/0)	W (82) (20/22/40)	W (59) (0/31/28)	W (75) (0/35/40)
4	Be (86) (20/26/40)	M (91) (20/40/31)	W (73) (0/33/40)	R (54) (20/34/0)	C (55) (20/29/7)	C (69) (20/38/11)	Br (60) (20/40/0)	Be (95) (20/35/40)	Br (60) (20/40/0)	M (68) (20/8/40)	M (52) (20/17/15)	Be (66) (0/26/40)
5	C (81) (20/25/36)	R (91) (20/40/31)	T (70) (20/17/34)	M (53) (20/33/0)	Be (51) (20/31/0)	Be (65) (20/40/5)	R (60) (20/40/0)	Br (88) (20/31/38)	R (60) (20/40/0)	R (60) (20/0/40)	T (43) (20/14/9)	C (63) (0/25/38)
6	Br (80) (20/22/38)	Be (77) (0/40/37)	R (67) (20/12/35)	Be (39) (0/39/0)	Br (47) (20/27/0)	M (63) (20/38/4)	W (60) (20/40/0)	C (87) (20/31/36)	W (60) (20/40/0)	C (53) (0/13/40)	C (41) (0/21/19)	Br (62) (0/22/40)
7	S (78) (20/22/36)	Br (72) (0/40/32)	Be (63) (0/23/40)	Br (34) (0/34/0)	S (47) (20/27/0)	S (63) (20/39/4)	C (59) (20/39/0)	R (86) (20/28/38)	C (59) (20/39/0)	Be (49) (0/9/40)	Be (39) (0/21/18)	M (60) (0/22/38)
8	M (77) (20/22/36)	C (72) (0/40/32)	C (58) (0/23/34)	C (34) (0/34/0)	M (46) (20/26/0)	Br (60) (20/40/0)	M (59) (20/39/0)	S (85) (20/30/36)	M (59) (20/39/0)	S (48) (0/8/40)	R (34) (20/9/6)	S (60) (0/22/38)
9	R (74) (20/16/39)	S (71) (0/40/31)	Br (55) (0/19/36)	S (33) (0/33/0)	R (43) (20/23/0)	R (60) (20/40/0)	S (59) (20/39/0)	M (84) (20/29/35)	S (59) (20/39/0)	Br (45) (0/5/40)	S (33) (0/18/15)	T (60) (0/20/40)
10	T (56) (0/19/37)	T (70) (0/40/30)	S (53) (0/20/34)	T (33) (0/33/0)	T (25) (0/25/0)	T (40) (0/40/0)	T (40) (0/40/0)	T (65) (0/29/36)	T (40) (0/40/0)	T (42) (0/2/40)	Br (30) (0/17/13)	R (56) (0/16/40)

Ba, Barley; Be, Beet; W, Wheat; Bf, Barley (Forage); C, Celery; Br, Broccoli; S, Spinach; M, Maize (Forage); R, Paddy rice; T, Tomato.
If the score was the same, crops were listed in alphabetical order.
[†]Information of RTLs are provided in Table 1.
[‡]Total score.
[§]Score for soil texture, soil salinity (EC_e), and water salinity (EC_w), respectively.

RTLs (Table 7).

Among the crops, barley and wheat (winter crops) were high ranked due to their high tolerance to soil and water salinity (Table 4) as well as wide suitability to soil texture (Table 3). Compared to other summer crops, when soil texture was suitable, beet, celery, and maize were high ranked due to their salinity tolerance at a higher salinity range (Table 4). Though paddy rice is currently widely cultivated in the 12 RTLs under waterlogged conditions through continuous irrigation that allow leaching of excessive salts during rice growth (Lim et al., 2020), the suitability score was <70 in nine RTLs except for BJ, GH, and SM mostly due to high EC_e and EC_w. As shown in Table 4, rice is not tolerant to salinity stress, and thus rice yield is reported to decrease EC_e above 3.0 dS m^{-1} and loses 50% yield at 6 - 7 dS m^{-1} (Maas and Hoffman, 1977; Abrol et al., 1988). For RTLs in South Korea, Lim et al. (2020) reported that white rice yield decreased with increasing salinity in an exponential manner.

As rice is a staple food in South Korea, the important role of RTLs to produce rice should not be ignored, and thus it is suggested to cultivate rice in three RTLs (BJ, GH, and SM) with high (>70) score for rice as a summer crop (Table 7). However, in the remaining nine RTLs, other crops such as beet (BJ, IW, NP, and YS 3-2), celery (BJ, IW, NP, and YS 3-2), and maize (GN, SS, and YS 3-1) are suggested as summer crops. For winter crops, barley (including forage) and wheat are suitable for all the RTLs.

Conclusions

This study shows that not only soil salinity but also soil texture and water salinity are necessary to be considered for the evaluation of crop suitability for cultivation in RTLs. Unexpectedly, the suitability score of rice was low for some RTLs and many other crops was ranked higher than rice. Therefore, in such RTLs, it may be possible to consider other crops including beet, celery, and maize as alternative summer crops to rice. For winter crops, barley and wheat were highly suitable for all RTLs. In addition, it may be also possible to increase crop yield by ameliorating soil texture, soil salinity, and water salinity for the target crops. However, in this study, as crop suitability was evaluated using average data of soil texture and salinity from selected fields in each RTL, it is necessary to use the data set specific to a field to recommend suitable crops for each field considering heterogeneity of soil properties among fields in a RTL. Furthermore, as soil and water salinity may decrease with time through natural and artificial desalinization, crop suitability assessment should be updated in the future to reflect changed soil and water salinity.

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