Research article

Growth and Mineral Uptake of *Moringa oleifera* Lam. in Low-Permeability Soils at Different Salinity Levels

TAKASHI KUME*
Graduate School of Agriculture, Ehime University, Matsuyama, Japan
Email: kume@ehime-u.ac.jp

CHULEEMAS BOONTHAI IWAI
Department of Agriculture, Khon Kaen University, Khon Kaen, Thailand

TETSUYA SHIMAMURA
Graduate School of Agriculture, Ehime University, Matsuyama, Japan

SHINSUKE HARUTA
Graduate School of Agriculture, Ehime University, Matsuyama, Japan

Received 24 July 2023 Accepted 1 October 2023 (*Corresponding Author)

Abstract This study investigated the uptake of minerals by moringa (*Moringa oleifera* Lam.) and examined the salt tolerance of moringa under different salinity treatments (0, 4, 8, and 16 dS/m). The effect of root growth on soil permeability at different salinity levels was also examined. Moringa showed significant negative effects of salinity on growth parameters at 8 dS/m. Significant growth inhibition was observed for moringa at 16 dS/m. The higher C/F ratios, calculated as (assimilated organ mass)/ (non-assimilated organ mass), in moringa in the 16 dS/m treatment may be due to the inhibition of nitrogen uptake by the roots, causing photosynthesis in the leaves to produce assimilates to sustain the body of the tree. In each moringa organ, the Na concentration increased as salinity increased. Significant differences in concentration were observed for Ca and K in leaves and Fe in stems at different salinity levels. The correlation analysis showed that only Mg and P in the branches and Fe and Mg in the stems were significantly negatively correlated with Na concentration, suggesting that increases in Na concentration cause limited inhibition of mineral uptake by moringa. A significant positive correlation was found between Na and P in the roots. It was suggested that moringa roots may have promoted growth by increasing P uptake in response to increased Na. There was a positive correlation between the length of moringa main roots and saturated hydraulic conductivity. The saturated hydraulic conductivity of the soil without moringa cultivation was 1.1×10^{-6} cm/s, and moringa root growth increased the saturated hydraulic conductivity by two orders of magnitude (10^{-4} cm/s) at 0 and 4 dS/m and by one order of magnitude (10^{-5} cm/s) at 8 and 16 dS/m.

Keywords moringa, soil salinity, root growth, mineral uptake, soil permeability

INTRODUCTION

Soil salinity is a major threat to land globally, and 833 million ha of soil is affected by salt (FAO, 2021). Coastal paddy fields in the Tohoku region were salinized by the tsunami caused by the Great East Japan Earthquake. In addition to natural disasters, coastal areas are also said to be widely affected by salt damage due to sea level rise caused by climate change. In addition, it has been calculated that the saline front will move up to 20 km upstream of the Mekong Delta in the 2030s due to climate change (Khang et al., 2008).

Saline soils need to be amended by improving soil permeability to discharge salts from soil layers. It is known that tree roots, such as *Alnus* Mill. roots, enhance soil permeability (Vergani and Graf, 2015). However, other studies suggest that the effect of trees and roots on soil permeability depends on soil type, soil and land use history, and vegetation cover type (Bonell et al., 2010). Therefore, the effect of each plant on the improvement of soil permeability should be investigated.

Moringa (*Moringa oleifera* Lam.) is highly salt tolerant, and all parts of moringa can be used for multiple purposes (Horn et al., 2022). Moringa seedlings survived up to 8 dS/m with a slight reduction in biomass chlorophyll a, crude protein, and mineral concentrations with increasing salinity (Nouman et al., 2012). Two-month-old moringa transplants might be NaCl tolerant up to 8 dS/m (Elhag and Abdalla, 2014). Farooq et al. (2022) investigated the impact of various salinity levels on the root attributes of moringa and revealed higher salinity levels (7.5 dS/m and 11.5 dS/m) significantly minimized the root surface area compared to 1.5 dS/m and 3.5 dS/m. These results show that salt tolerance has been studied, but a comprehensive assessment of mineral concentrations of moringa under saline conditions has not been completed. Research on root growth parameters has been conducted; however, the effect of moringa root growth on the improvement of soils has not been examined.

OBJECTIVE

This study investigates the growth and mineral uptake of moringa and the salt tolerance of moringa at different salinity levels. Root growth and its effect on soil permeability in soils with different salinity levels were also examined.

METHODOLOGY

A cultivation experiment was conducted in a greenhouse for two months. Root boxes (width: 60 cm, height: 40 cm, depth: 10 cm) made of acrylic plates were used for the cultivation experiments. The root boxes were filled with a 20-cm-deep plow layer and a 10-cm-deep plow layer, as shown in Table 1. The soil texture of paddy soil was CL (Clay Loam) and the soil hydraulic conductivity of two layers of soil as shown in Table 1 was 1.1×10^{-6} cm/s.

Table 1 Physical properties of soils in the cultivation experiment

	Dry bulk density (Mg/m^3)	Particle density (Mg/m^3)	A mixing ratio of experimental soil	
			Paddy soil (CL)	Gravel
Plow layer	1.2	2.53	100%	0%
Plow sole layer	1.7	2.59	75%	25%

The soils were subjected to four salinity treatments: one without NaCl (0 dS/m) and three with NaCl added to the soil to adjust the soil salinity to EC_e = 4, 8, and 16 dS/m. Indian moringa seeds were used, and a total of 24 sample trees were grown, with six moringa tree replications in each salinity treatment. 10 mm irrigation water was supplied when the soil surface was dried, and no fertilizer was used.

Growth parameters (tree height and dry matter (DM) weight of leaves, branches, stems, and roots) were measured. Dry matter weights were determined after samples were oven-dried at 80 °C for 48 hours. The C/F ratio was calculated as the (assimilated organ mass) ÷ (non-assimilated organ mass), and the aerial C/F ratio was calculated as (assimilated organ mass) ÷ (aboveground non-assimilated organ mass); these ratios were used as indices to describe the structure of material production systems (Nomoto and Yokoi, 1981).

The mineral concentrations in each organ of the harvested moringa were determined by ICP optical emission spectrometry (Varian, Vista-MPX). A soil permeability experiment was performed after harvesting the aboveground portions of the moringa plants, with the roots remaining in the root box. The root box was placed in a bucket filled with water and it was capillary saturated, then water was ponded to a depth of 10 cm, and changes in water level over time were recorded. The measured data were substituted into Darcy's equation to obtain the saturated soil hydraulic conductivity. ANOVA was performed at the 5% significance level for the height, dry matter, and mineral concentration of each part of moringa grown under each salinity condition. When the ANOVA showed significant differences, multiple comparisons (Tukey test) were used to test between samples.

RESULTS AND DISCUSSION

Effect of Salinity Treatments on Growth Parameters

Significant differences were found in tree height, root dry matter weight, total dry matter weight, and the C/F ratio under different salinity levels (Table 2). There were no significant differences between 0 dS/m and 4 dS/m in any of the parameters. All the parameters except the CF/ratio at 8 dS/m had significantly smaller values than those at 0 and 4 dS/m. All the parameters except the C/F ratio at 16 dS/m had significantly smaller values than those at the other salinity levels. The C/F ratio at 16 dS/m (0.346) was significantly larger than that at 4 dS/m (0.164). Noumen et al. (2012) showed that moringa was able to survive under 8 dS/m conditions with little reduction in nutritional value. Elhag and Abdalla (2014) showed that moringa is salt tolerant up to 8 dS/m, with significantly lower values for tree height and leaf dry weight at 16 dS/m. Farooq et al. (2022) also concluded from their experiment results that germination rate, root surface area, and aboveground growth are largely unaffected at salinity levels up to 3.5 dS/m. Our results were similar to those of previous studies.

Table 2 Effects of salinity treatments on growth parameters

Different letters indicate significant difference at $p < 0.05$ (DM: dry matter)

Salinity treatment	Tree height (cm)	Leaf DM (g)	Branch DM (g)	Stem DM (g)	Root DM (g)	Total DM (g)	C/F ratio	Aerial C/F ratio
0 dS/m	53.5±7.9ab	2.020±0.35	0.977±0.20	2.470±0.62	9.45±2.20ab	14.9±2.6ab	0.164±0.02a	0.711±0.10
4 dS/m	63.5±7.1a	2.390±0.49	1.110±0.28	2.960±0.73	10.20±1.40a	16.7±2.1b	0.164±0.01a	0.650±0.10
8 dS/m	52.5±8.5ab	1.890±0.70	1.030±0.40	2.760±1.20	4.15±0.88b	9.78±2.5a	0.199±0.04ab	0.555±0.04
16 dS/m	27.5±3.9b	0.812±0.20	0.307±0.12	0.650±0.24	1.42±0.40c	3.18±0.1c	0.346±0.09b	0.925±0.20

Mean ± standard deviation (Data adopted from Kume et al., 2023)

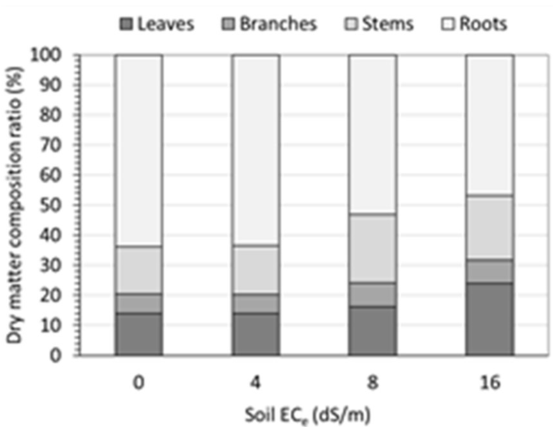

Fig. 1 Composition of dry matter weight by the organ of moringa grown at different salinity levels

The compositions of moringa organs at 0 dS/m and 4 dS/m were similar, while the percentages of moringa organ dry matter weights at 8 dS/m were approximately the same as those at 0 dS/m, with a 7% increase in stem dry matter weight and a 10% decrease in root dry matter weight (Fig. 1). Moringa in the 16 dS/m treatment had 10% greater leaf dry matter weight, 2% greater branch dry matter weight, 5% greater stem dry matter weight, and 17% lower root dry matter weight than moringa in the 0 dS/m treatment, with a significant difference in the C/F ratio (0.164 at 0 and 4 dS/m compared to 0.346 at 16 dS/m). The aerial C/F ratios were not significantly different among the salinity levels. Carbon is acquired by aboveground plant parts, and nitrogen is acquired by belowground plant parts (Hirose, 1988). Individuals showing abnormally high C/F ratios are thought to die due to an imbalance between assimilated and non-assimilated organs (Higo, 1987). Moringa in the 16 dS/m soil, where growth inhibition was observed, showed a significantly higher C/F ratio than moringa in the other treatments, and that photosynthesis in the leaves produces assimilates to sustain the body of the tree.

Mineral Uptake by Moringa

The Na concentrations in the organs were significantly different among the different salinity levels (Table 3). In each moringa organ, the Na concentration increased as salinity increased. Tukey's test showed no significant differences in Na concentration between the 0 dS/m treatment and 4 dS/m treatment for all organs. In leaves, branches, and stems, the Na concentrations at 8 dS/m and 16 dS/m were significantly different from those at 0 dS/m. For roots, the Na concentration at 8 dS/m was significantly different from that at 0 dS/m and 4 dS/m, and the Na concentration at 16 dS/m was significantly different from those at the other salinity levels.

Table 3 Mean values of mineral concentrations in each organ of moringa grown at various salinity levels

*Different letters indicate significant difference at p < 0.05 (*DM*: dry matter)*

	Salinity treatment	Na mg/g DM	K mg/g DM	Ca mg/g DM	Fe mg/g DM	P mg/g DM	Mg mg/g DM	Cu μg/g DM	Zn μg/g DM
Leaves	0 dS/m	1.110±0.21a	24.9±1.4a	8.69±0.89ab	0.166±0.05	7.72±0.86	3.18±0.25	11.3±2.7	50.1±17.0
	4 dS/m	0.958±0.13a	21.7±1.9a	10.10±1.20a	0.122±0.09	6.24±0.70	2.58±0.35	10.3±0.9	44.8±8.8
	8 dS/m	2.410±0.30b	18.5±0.7ab	7.90±0.36ab	0.183±0.05	5.79±0.91	2.66±0.40	13.8±4.2	82.7±25.0
	16 dS/m	1.890±0.35ab	14.2±2.1b	6.10±0.50b	0.120±0.02	5.42±0.87	2.61±0.36	8.03±0.7	34.9±4.3
Stems	0 dS/m	0.574±0.08a	24.2±2.3	11.10±1.4	0.538±0.08a	7.21±0.86	3.21±0.50	9.82±0.9	55.8±6.6
	4 dS/m	1.570±0.16a	18.9±1.3	9.95±1.10	0.479±0.01a	6.58±0.60	3.12±0.31	10.3±1.4	57.8±13.0
	8 dS/m	3.930±0.68b	19.5±2.8	10.90±1.10	0.115±0.05b	5.02±0.10	2.14±0.21	11.3±1.7	69.3±20.0
	16 dS/m	4.670±0.62b	25.5±7.0	10.10±0.67	0.142±0.02b	6.38±1.20	1.94±0.21	14.1±2.2	73.3±13.0
Branches	0 dS/m	0.499±0.10a	30.2±1.8	10.50±1.20	0.171±0.04	9.13±0.35	1.73±0.28	13.2±1.7	80.0±18.0
	4 dS/m	1.240±0.15a	25.9±1.3	11.80±1.20	0.109±0.01	8.66±0.43	1.68±0.21	9.11±2.5	56.4±21.0
	8 dS/m	3.870±0.80b	31.6±3.7	8.33±0.52	0.114±0.04	6.66±0.80	1.07±0.10	6.02±0.7	41.0±4.6
	16 dS/m	4.680±0.62b	24.5±3.0	10.60±2.60	0.172±0.08	8.04±1.30	1.23±0.12	8.83±2.5	48.6±8.9
Roots	0 dS/m	0.768±0.11a	13.7±1.1	6.23±0.95	0.716±0.03	4.38±0.32	3.25±0.24	14.7±1.2	91.3±17.0
	4 dS/m	1.550±0.12a	12.4±0.7	5.30±0.59	0.560±0.01	5.00±0.27	2.31±0.15	12.6±1.6	63.2±14.0
	8 dS/m	5.650±0.75b	13.8±1.3	5.36±0.74	0.714±0.07	5.02±0.47	2.38±0.13	12.4±0.1	75.9±11.0
	16 dS/m	9.070±0.84c	13.3±2.0	5.58±0.48	1.040±0.20	6.68±1.00	2.89±0.33	15.5±1.8	78.9±15.0

Apart from Na, significant differences in concentration were observed for Ca and K in leaves and Fe in stems. For these values, the concentration decreased with increasing salinity. Cu, Mg, P, and Zn did not show significant differences among organs or salinity levels. In leaves, the Na concentration increased and the K concentration decreased with increasing soil salinity. Mg and P in the branches and Fe and Mg in the stems showed a decreasing trend in response to increasing Na (Table 4). The P concentration increased with increasing Na concentration in the roots. There was no correlation between Na and other minerals. The P concentration was significantly correlated with various ion concentrations in all organs. The P concentration was significantly positively correlated with Ca, Cu, Fe, and K in leaves; with Ca, Cu, Fe, Na, and Zn in branches; with Fe, K, and Mg in stems; and with K, Mg, and Na in roots. In branches, the Ca concentration was significantly positively correlated with Cu, Fe, Mg, P, and Zn, and the Cu concentration was significantly positively correlated with Fe, Mg, P, and Zn.

Table 4 Correlation matrix of mineral concentrations in each organ

		Ca	Cu	Fe	K	Mg	Na	P	Zn
	Ca	-	0.28	0.19	0.57	0.15	-0.20	0.46	0.16
	Cu		-	0.85	0.10	0.15	0.05	0.44	0.96
	Fe		*	-	0.10	0.19	0.05	0.67	0.83
Leaves	K	*			-	0.33	-0.06	0.67	0.05
	Mg					-	0.06	0.23	0.10
	Na						-	-0.02	0.22
	P	*	*	*	*			-	0.35
	Zn		*	*					-
		Ca	Cu	Fe	K	Mg	Na	P	Zn
	Ca	-	0.71	0.78	-0.36	0.66	-0.11	0.54	0.57
	Cu	*	-	0.75	-0.08	0.80	-0.35	0.55	0.89
	Fe	*	*	-	-0.18	0.59	-0.05	0.42	0.52
Branches	K				-	-0.10	-0.21	0.00	0.06
	Mg	*	*	*		-	-0.47	0.48	0.78
	Na					*	-	-0.45	-0.30
	P	*	*	*		*	*	-	0.43
	Zn	*	*	*		*		*	-
		Ca	Cu	Fe	K	Mg	Na	P	Zn
	Ca	-	-0.31	0.24	-0.17	0.67	0.11	0.19	-0.32
	Cu		-	-0.22	0.56	-0.22	0.31	0.27	0.91
	Fe			-	0.05	0.58	-0.57	0.42	-0.21
Stems	K		*		-	-0.01	-0.05	0.68	0.31
	Mg	*		*		-	-0.42	0.56	-0.15
	Na			*		*	-	-0.25	0.19
	P			*	*	*		-	0.09
	Zn		*						-
		Ca	Cu	Fe	K	Mg	Na	P	Zn
	Ca	-	0.13	-0.07	0.42	0.50	-0.11	0.20	0.06
	Cu		-	0.37	0.07	0.28	0.17	0.09	0.74
	Fe			-	-0.12	0.12	0.32	-0.02	0.40
Roots	K	*	*		-	0.58	0.14	0.65	-0.13
	Mg	*			*	-	0.08	0.45	0.16
	Na						-	0.63	-0.01
	P				*	*	*	-	-0.25
	Zn		*						-

** Indicates a significant correlation coefficient at $p < 0.05$.*

In the study by Elhag and Abdalla (2014), leaf Ca and K in moringa also decreased with increasing Na concentration. Increases in Na have been found to decrease K in triticale, barley, and rice (Flowers and Hjibagheri, 2001; Naidoo, 2007). There were no significant differences in the concentrations of P, Cu, Mg, and Zn. Matsumaru (1990) found no clear relationship between Fe, Mn, and Zn concentrations and increasing salinity in a cucumber salt tolerance experiment. The results of the correlation analysis in this study also showed that only Mg and P in the branches and Fe and Mg in the stems were significantly negatively correlated with Na concentration, suggesting that increases in Na concentration cause limited inhabitation of mineral uptake by moringa. A significant positive correlation was found between Na and P in the roots. The same results were obtained by Elhag and Abdalla (2014) and Nouman (2012). It was suggested that moringa roots may have functioned to promote growth by increasing P uptake in response to increased Na.

Root Growth and Soil Permeability

There was a positive correlation between the length of moringa main roots and saturated hydraulic conductivity in the salinity-treated soils (Fig. 2). The relationship between the circumference of the main root and saturated hydraulic conductivity was highly positive (Fig. 3). The saturated hydraulic conductivity of the soil without moringa was 1.1 × 10^{-6} cm/s, and moringa root growth increased the saturated hydraulic conductivity by two orders of magnitude (10^{-4} cm/s) at 0 and 4 dS/m and by one order of magnitude (10^{-5} cm/s) at 8 and 16 dS/m. *Sophora japonica* has tap roots, which grow relatively deep and vertically; these roots loosen the soil more deeply and greatly increase soil infiltration rates (Zhang et al., 2019). *Alunus incana* roots were shown to improve soil permeability (Vergani and Graf, 2015). The length and circumference of the main root were greatest at 0 dS/m and 4 dS/m. The circumference was 13.1 cm and 13.9 cm at 0 and 4 dS/m, respectively, and 6.8 cm at 16 dS/m, approximately half of that at 4 dS/m. There was a strong positive correlation between root dry weight and the length and circumference of the main root in each treatment (length: $r = 0.99$, $p = 0.0006$; circumference: $r = 0.98$, $p = 0.001$).

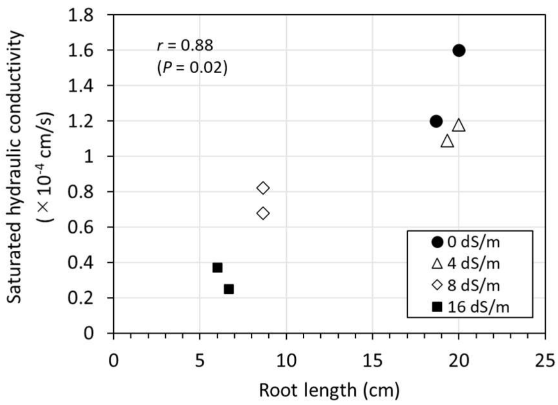

Fig. 2 Relationship between root length and saturated hydraulic conductivity

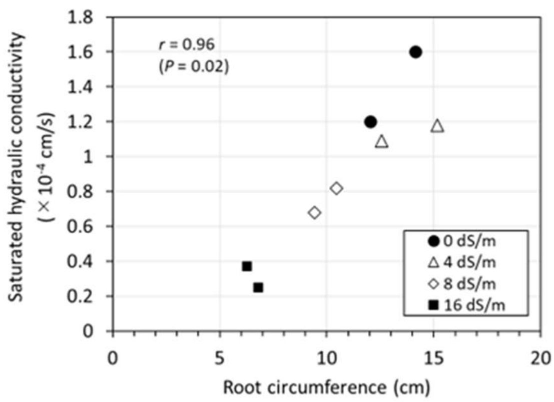

Fig. 3 Relationship between root circumference and saturated hydraulic conductivity

CONCLUSION

Moringa has high salt tolerance and can be grown in paddy soils up to 8 dS/m with almost no growth inhibition. As soil salinity increased, Na concentrations in each moringa organ also increased. The results of the correlation analysis in this study also showed that only Mg and P in the branches and Fe and Mg in the stems were significantly negatively correlated with Na concentration, suggesting that increases in Na concentration cause limited inhabitation of mineral uptake by moringa. There was a strong positive correlation between the length of moringa main roots and saturated hydraulic conductivity, the results showed that moringa root growth increased the soil permeability.

ACKNOWLEDGEMENTS

This research was financially supported by The Mitsui & Co. Environment Fund and JSPS KAKENHI 21H03692.

REFERENCES

Bonell, M., Purandara, B.K., Krishnaswamy, J., Acharya, H.A.K., Singh, U.V., Jayakumar, R. and Chappell N. 2010. The impact of forest use and reforestation on soil hydraulic conductivity in the Western Ghats of India, Implications for surface and sub-surface hydrology. Journal of Hydrology, 391, 47-62, Retrieved from DOI https://doi.org/10.1016/j.jhydrol.2010.07.004

Elhag, A.Z. and Abdalla MH. 2014. Investigation of sodium chloride tolerance of moringa (*Moringa oleifera* Lam.) transplants. Universal Journal of Agricultural Research, 2 (2), 45-49, Retrieved from DOI https: //doi.org/10.13189/ujar.2014.020202

FAO. 2021. Global map of salt-affected soils (GSASmap). Retrieved from URL https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-map-of-salt-affected-soils/en/

Farooq, F., Rashid, N., Ibrar, D., Hasnain, Z., Ullah, R. and Nawaz, M. 2022. Impact of varying levels of soil salinity on emergence, growth and biochemical attributes of four *Moringa oleifera* landraces. PLoS ONE 17 (2), e0263978, Retrieved from DOI https://doi.org/10.1371/journal.pone.0263978

Flowers, T.J. and Hajibagheri, M.A. 2001. Salinity tolerance in *Hordeum vulgare*, Ion concentrations in root cells of cultivars differing in salt tolerance. Plant and Soil, 231, 1-9, Retrieved from DOI https://doi. org/10.1023/A:1010372213938

Higo, M. 1987. Growth characteristics of *Quercus mongolica var. grosseserrata*, *Tilia japonica*, and *Acer mono* seedlings. Research Bulletin of the Hokkaido University Forests, 44 (1), 139-152. (in Japanese)

Hirose, T. 1988. Nitrogen availability, optimal shoot/root ratios, and plant growth. In Werger, M.J.A., van der Aart, P.J.M., During, H.J. and Verhoven J.T.A (Eds.), Plant form and vegetative structure. 135-145, SPB Academic Publishing, The Hague, the Netherlands.

Horn, L., Shakela, N., Mutorwa, M.K., Naomab, E. and Kwaambwa, H.M. 2022. *Moringa oleifera* as a sustainable climate-smart solution to nutrition, disease prevention, and water treatment challenges, A review. Journal of Agriculture and Food Research. 10, 100397, Retrieved from DOI https://doi.org/10. 1016/j.jafr.2022.100397

Khang, N.D., Kotera, A., Sakamoto, T. and Yokozawa M. 2008. Sensitivity of salinity intrusion to sea level rise and river flow change in Vietnamese Mekong Delta, Impacts on availability of irrigation water for rice cropping. Journal of Agricultural. Meteorology, 64 (3), 167-176, Retrieved from DOI https://doi.org/10. 2480/agrmet.64.3.4

Kume, T., Shimamura, T. and Haruta, S. 2023. Changes in growth parameters of *Moringa oleifera* Lam. and soil physical property under different salinity treatments. International Journal of Agriculture & Biology, 29 (05), 345-350, Retrieved from DOI https://doi.org/10.17957/IJAB/15.2039

Matsumaru, T. 1990. Salt injury of vegetables and greenhouse, Effect of sodium chloride accumulation in soils on the growth and the inorganic components of cucumber plants. Bulletin of the Chiba-Ken Agricultural Experiment Station, 31, 19-26. (in Japanese)

Naidoo, G., Somaru, R. and Achar, P. 2008. Morphological and physiological responses of the halophyte, *Odyssea paucinervis* (Staph) (Poaceae), to salinity. FLORA, 437-447, Retrieved from DOI https://doi.org/ 10.1016/j.flora.2007.08.003

Nomoto, N. and Yokoi, Y. 1981. Material production in plants. Tokai University Press. (in Japanese)

Nouman, W. M.T., Siddiqui, S.M.A., Basra R.A., Khan T., Gull M.E., Olson and H. Munir. 2012. Response of *Moringa oleifera* to saline conditions. International Journal of Agriculture and Biology, 14, 757-762.

Vergani, C. and Graf, F. 2015. Soil permeability, aggregate stability, and root growth, A pot experiment from a soil bioengineering perspective. Ecohydrology, 9 (5), 830-842, Retrieved from DOI https://doi.org/10. 1002/eco.1686

Zhang, D., Wang, Z., Guo, Q., Lian, J. and Chen, L. 2019. Increase and spatial variation in soil infiltration rates associated with fibrous and tap tree roots. Water, 11, 1700, Retrieved from DOI https://doi.org/10. 3390/w11081700