Let’s insert capillary barrier in soil for salt-damage control and water-saving agriculture

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(a) Abstract

In addition to the water scarcity, the yearly cycle of dry and rainy seasons causes surface soil salinization to become major abiotic constrains limiting agricultural production in arid and semi-arid regions. Associated with the impacts of climate change, population booming and increasing global food demand, developing countries in these regions are experiencing severe food crisis. Although the practice of irrigated agriculture has substantially contributed the food production, the salinity issue remains as major challenge due to the evaporation. In light of these, in this research, we developed a low-cost water-efficient salinity prevention control system through capillary barrier (CB) for application in the arid and semi-arid regions through controlling the soil moisture movement. The objectives of this study were to introduce an artificial CB, which made up of lime (we selected calcium chloride, converter slag, and plant and wood ash for their relatively low-cost and practicality), gravel and plant residue, aiming (1) to suppress salts accumulation by elution of calcium as it permeates the CB and exchange with sodium which adsorbed on the soil, (2) to supply minerals to the infertile soils, and (3) to contribute to food production by reducing the loss of cultivated land due to high salinity. We found the salinization suppression without requiring huge amount of water by the application of gravel CB that effectively prevented the capillary action of agricultural crops by dissolving calcium in CB with the stored water. This low-cost and water-saving system will surely pave a new path for sustainable agriculture, especially for arid and semi-arid regions.

(b) Contents

(c) Abbreviations

EC: Electrical Conductivity (mS/cm)
CB: Capillary Barrier
CC: Calcium Chloride
CS: Converter Slag
PWA: Plant and Wood Ash

(d) Acknowledgement

We would like to express our deepest gratitude to the Arid Land Research Center of Tottori University on providing guidance in preparing salt-affected soils in the arid region and we would like to thank Aomori Prefectural Nakui Agricultural High School and others for providing the experimental cultivation site for this study.

(e) Self-introduction

Mizuho NAKAI

I am a third-year student from the department of environmental systems, Aomori Prefectural Nakui Agricultural High School. I was responsible for preparing the salt-affected soil, selection for lime material, and salinity damage control tests. Throughout this research, I have learned the impacts of water-induced salinity accumulation to the agricultural products and food insecurity in the arid and semi-arid regions. In the future, I wish to continue my research in this direction and contribute myself in solving the world's environmental issues.

Yuki TERASAWA

I am a third-year student from the department of environmental systems, Aomori Prefectural Nakui Agricultural High School. I am keen on contributing myself in addressing global issues, particularly on the salinity damage control. In this research, I am responsible to perform the ion exchange and characterization of CB. I would like to utilize the knowledge and experience that I gained in this research to address the environmental problems, particularly in the developing countries.

1. Introduction

Associated with the impacts of climate change, the increasing water stresses and desertification become growing concerns all over the world. In addition, the yearly cycle of dry and rainy seasons causes surface soil salinization to become major abiotic constrains limiting agricultural production in the arid and semi-arid regions, including Africa, Asia, America, and Australia (Fig.1), with a total affected area of approximately one billion hectares (Table 1) [1]. Soil salinity can be categorized into two groups, the saline soil (composed of salts that are water soluble and easily be crystalized) and the sodic soil (composed of excess sodium) [2]. In general, soil salinization can be induced by two factors, naturally induced in soil and water (known as primary salinization) and caused by anthropogenic activities such as irrigated agriculture and urbanization (known as secondary salinization). The damaged induced by the latter is much severe to the agricultural products, with an approximate of 20% of the agricultural land is impacted [3].

Fig. 1: Countries affected by soil salinization

Table 1: Area of soil salinization (million ha)

Continent	Saline soil	Sodic soil	Total
Africa	53.5	26.9	80.4
Asia	194.7	121.9	316.5
Americas	77.6	69.3	146.9
Australia	17.6	340.0	357.6
Europe	7.8	22.9	30.8
Whole world	351.2	581.0	932.2

Associated with the booming population and urbanization, Asia and Africa continents are particularly facing severe food insecurity issue. Although irrigated agriculture is practiced in these regions to improve the food production, severe salinity-induced damage occurs due to the lack of proper drainage management. This has increased groundwater level, leading to the formation of saline/sodic soils from the capillary movement of the saline groundwater (Fig. 2) or due to the evaporation of surface water (Fig. 3). Therefore, soil salinization occurs when the high salinity water was used for irrigation or drip-irrigation.

Based on the experience during the Great East Japan Earthquake in 2011, lime materials and large amount of water was found to have effectively removed salts from a 24,000 ha of tsunami-affected agricultural lands (Fig. 4). The Na^+ adsorbed on soil particles are replaced by Ca^{2+} from lime, and the Na^+ is washed away. However, 2,500 m^3 of water per affected hectare is required even for mild salinity damage [4], making it is not applicable for arid lands where water is scarce.

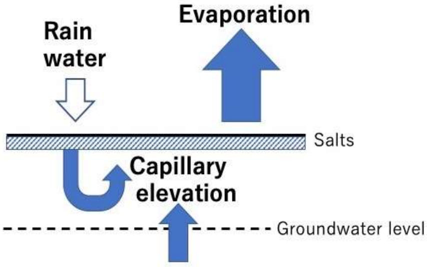


Fig. 2: Process of salinization.

Fig. 3: Salt affected agricultural land.

Fig. 4: Desalinization by leaching.

Therefore, we thought that a sustainable agricultural system is necessary to prevent salt damage in arid and semi-arid developing countries. Premised on the search for low-cost and reliable agricultural system, we took particular note on the use of capillary barrier (CB) for salinity damage prevention. The CB has been used in Japan since ancient times for rainwater infiltration in ancient tombs (Fig.5) [5]. In recent, this method has been introduced to prevent deterioration of radioactive waste storage facilities built from concrete structures [6]. This study intends to design and develop a capillary barrier, to block the capillary phenomenon by adding a layer of gravel to the soil. The proposed CB is a simple structure consisting of a fine-grained soil layer (*e.g.,* sand) and a coarse-grained soil layer (*e.g.,* gravel). The coarse-grained layer prevents the rainwater that has infiltrated by capillary movement from the fine-grained layer and stores it at the boundary layer.

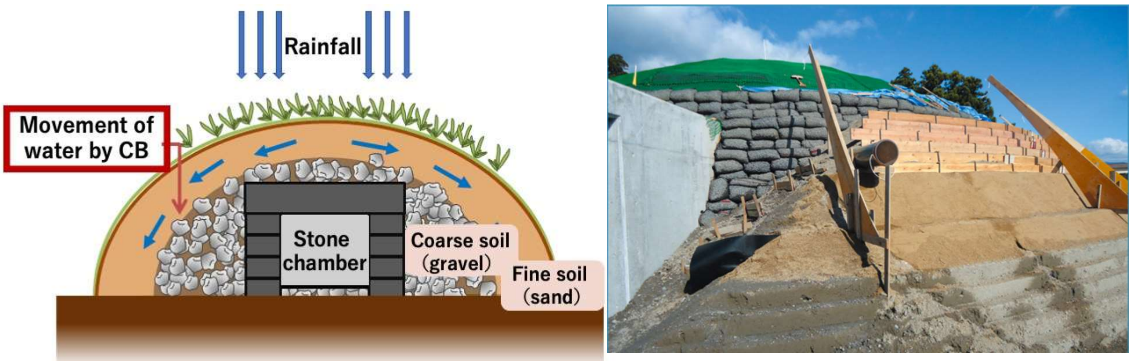


Fig. 5: Application of CB for water prevention in ancient tomb.

The idea of improving the current CB structure came up to our mind is the use of a mixture of lime materials such as calcium chloride (CC), converter slag (CS), and plant and wood ash (PWA) in gravel (Fig.6). Through the modified CB structure, the Ca^{2+} could be gradually eluted from the lime material and the Ca^{2+} will be replacing the Na^{+} adsorbed on soil particles.

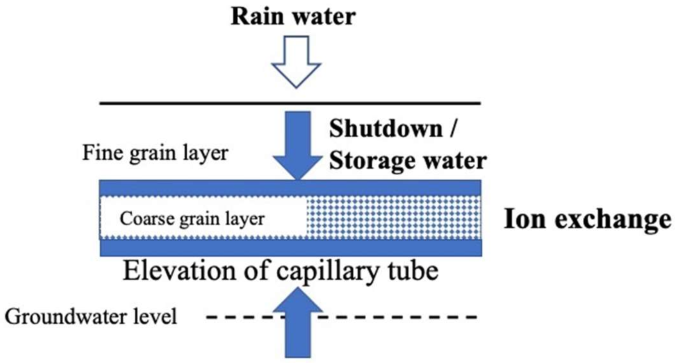


Fig. 6 Concept of desalinization by CB.

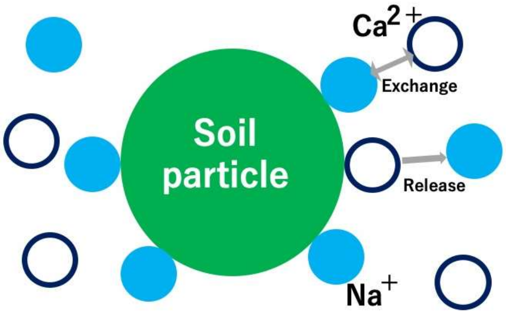


Fig. 7 Schematic drawing of ion exchange between Na^{+} and Ca^{2+}.

The purpose of this study was to evaluate whether a salinity control system that combines the effects of groundwater movement and CBs can control salt accumulation without the use of large amounts of water. The results showed that the technology has high potential to contribute to sustainable agricultural production in arid and semi-arid regions.

2. Materials and methods

2.1 Salt-affected soil

The salinization occurs in Uzbekistan, where salt-impacted soils are classified into four levels (Non, Low, Moderate and High) based on electrical conductivity (EC) [7]. Table 2 shows the salt-affected areas in the Oqoltin district suffer from low to middle salinity damage. So, in this research, we produced the low and middle salinity soils and used for experiments. In addition, as most of the soils in arid and semi-arid areas are a mixture of clay, silt, and sand [8], we produced the soils by mixing sand and clay in a ratio of 7:3 in volume. To ensure the adaptability of different soils, two types of clay with different cation exchange capacity (CEC); bentonite (high CEC) and kaolinite (low CEC). The sand used was a fine sandy soil with large grain size, which is formed by the wetting of granite. The salt-affected soil was mixed with a brine by dissolving NaCl in purified water, dried at 24°C, and mixed to avoid clumping. The soil mixture composition, pH and EC are shown in Table 3.

Table 2: Salt-affected areas in Oqoltin district, Uzbekistan (2008)

Irrigated area	Non (EC: <2 mS/cm)		Low (EC: 2-4 mS/cm)		Middle (EC: 4-8 mS/cm)		High (EC: >8 mS/cm)	
ha	ha	%	ha	%	ha	%	ha	%
43,692	551	1.3	32,495	74.4	9,412	21.5	1,234	3.8

Table 3: Composition, pH and EC for the low and middle salinity impacted soils

	Clay (3 L)	Soil (L)	NaCl (g)	pH	EC (mS/cm)
Low	Bentonite	7	253	10	2.0
	Kaolinite	7	22.9	8	2.5
Middle	Bentonite	7	322	9	9.0
	Kaolinite	7	252	8	7.5

2.2 Lime materials

In this study, to suppress soil salinization, we used three types of lime materials, CC (Hayashi Pure Chemical Ind., Ltd.), PWA (Akimata Fisheries Factory Co., Ltd.), and CS (Minex Co., Ltd.), to form CB. CC was selected because it is inexpensive and widely available. PWA was selected because it can be easily produced by incinerating dead leaves and trees. CS is a byproduct of the steelmaking process and contains calcium silicate and calcium oxide, as well as iron and magnesium. The composition of grass ash and converter slag are shown in Table 4.

Table 4: Types of lime materials and their composition (%).

Type	N	PO_4-P	K	CaO

PWA	0.04	2.3	6.1	11

Type	SiO_2	Fe	Ca	Mg	Al	Mn
CS	15.0	20.0	38.2	4.0	3.1	3.0

2.3 Experimental methods

2.3.1 Leaching of lime materials

100 g of CC, PWA, and CS was immersed in a beaker containing 1 L of purified water and placed in a 24°C incubator (Table 5). The samples were covered with plastic wrap to prevent evaporation (Fig. 8). We then analyzed pH, EC, Ca, and Na at 1 h, 2 h, 4 h, 8 h, 24 h, 7 d, and 35 d after the initiation of the experiment.

Table 5: Lime material to water ratio in the leaching experiments.

Experiment Plot	Amount (g)	Water Volume (L)
CC	100	1
PWA	100	1
CS	100	1
Control	-	-

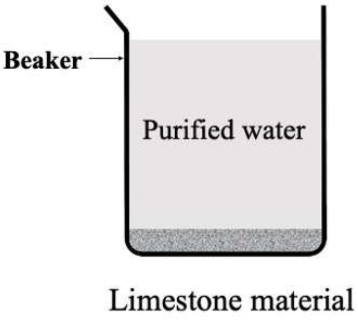


Fig.
leach

2.3.2 Ion exchange

100 g of low and middle salinity affected soils of bentonite and kaolinite are mixed in 1 L of purified water with 10 g of each lime material (Table 6). We covered the beakers w with plastic wrap to prevent evaporation, placed in a stationary incubator at 24°C, and analyzed pH, EC, Ca, and Na at 1 h, 2 h, 4 h, 8 h, 24 h, 7 d and 35 d after the initiation of the test.

Table 6: Composition for each experimental plot in the ion exchange

<Low salinity affected soil>

Test Plot	Lime Material	Low
LB-CC	CC 10 g	Bentonite 100 g
LB-PWA	PWA 10 g	
LB-CS	CS 10 g	
LB	Non	

Test Plot	Lime Material	Low
LK-CC	CC 10 g	Kaolinite 100 g
LK-PWA	PWA 10 g	
LK-CS	CS 10 g	
LK	Non	

<Middle salinity affected soil>

Test Plot	Lime Material	Middle
MB-CC	CC 10 g	Bentonite 100 g
MB-PWA	PWA 10 g	
MB-CS	CS 10 g	
MB	Non	

Test Plot	Lime Material	Middle
MK-CC	CC 10 g	Kaolinite 100 g
MK-PWA	PWA 10 g	
MK-CS	CS 10 g	
MK	Non	

2.3.3 Effect of CBs on salt damage suppression

A 5 cm diameter plastic bottle with the bottom cut off was stood upside down and filled with 50 mL of purified water (to resemble groundwater). The bottle was filled up to 15 cm above its water level with the middle salinity affected soil made of Akadama clayey soil and sand in a ratio of 7:3 in volume (Fig. 9). Three types of CB were constructed on top of the soil with a thickness of 1 cm. 15 cm of soil without NaCl was also filled on top of it, and 15 mL of purified water was poured from the top. To represent the rainy season in Uzbekistan, we poured 15 mL of purified water from the top every 3 d and kept an incubator at 27°C [9]. Then, we measured every 3 d to determine the weight of the bottle before watering, soil moisture at a depth of 2 cm from the topsoil, the height of the groundwater table, and the depth of the infiltration from the topsoil (Fig. 10). We also measured the pH, EC, Na, and Ca of the topsoil were also analyzed after 2 and 4 weeks. After another 4 weeks, we analyzed the moisture content of the CB at 3 cm above and below, and the soil at 3 cm below the CB. The composition of the middle salinity affected soil and CB materials are shown in Tables 7 and 8, respectively.

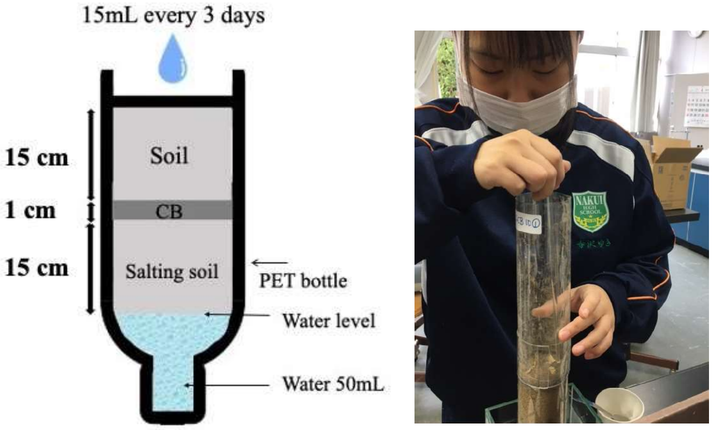


Fig. 9: Salt damage evaluation in schematic (left) and real setup (right).

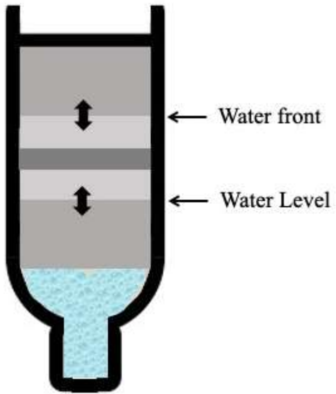


Fig. 10: Groundwater level and infiltration front.

Table 7: Properties of mildly saline and non-additive control soils.

Soil	Composition	pH	EC (mS/cm)	Na (mg/L)	Ca (mg/L)

Low salinity soil	Akadama soil:sand (7:3)	8.0	2.1	310	29
Na-free soil		7.4	0.05	3	8

Table 8 CB materials and its composition (1 cm thick, 20 cm^2).

Type of CB	Lime Material	Plant Residue (rice straw)	Gravel
CC-CB	12.5 mL	5 mL	7.5 mL (about 1 cm in diameter)
PWA-CB			
CS-CB			
N	-	-	-

Fig.11: Photographs of gravel (left) and plant residue (right)

2.4 Seedlings Cultivation

To evaluate the performance of CB for soil salinization prevention, we conducted cultivation experiments by crop growth conditions. We planted lettuce *(Lactuca sativa L.*) seedlings in PET bottles under same experimental conditions as described in 2.3.3. Salt damage control test, and their growth was observed using the same method (Fig. 12).

Fig. 12: Cultivation management

2.5 Analytical methods

We measured the pH, EC, Na, Ca, Cl and soil moisture using LAQUAtwin-pH-11B (Horiba), LAQUAtwin-EC-33B (Horiba), LAQUAtwin-Ca-11 (Horiba), LAQUAtwin-Na-11 (Horiba), DPM-MT (KYORITSU CHEMICAL-CHECK Lab,Corp), respectively. We also measured soil moisture using a soil moisture meter (DM-18R, Takemura Electric Mfg. Co., Ltd.).

3. Results and Discussion

3.1 Experiments on leaching of lime materials

Fig. 13 shows the trend of water quality. pH increased to about 12 for PWA and CS, which is due to the elution of the strongly basic calcium oxide contained in these lime materials. The high water solubility of CC caused a large increase in Ca concentration. On the other hand, the water solubility of CaO in the PWA and CS was relatively low and therefore the increment was limited. Although the water solubility of calcium silicate (main component of CS) is low (approximately 100 mg/L), it may have increased slowly because it contains about 38% Ca, more than three times that of PWA. In summary, we found that CC, PWA, and CS will leach Ca, indicating that they are likely to be used as lime materials for CBs. Besides that, although Na is contained to a certain extent in PWA, it is low enough and does not cause salt damage.

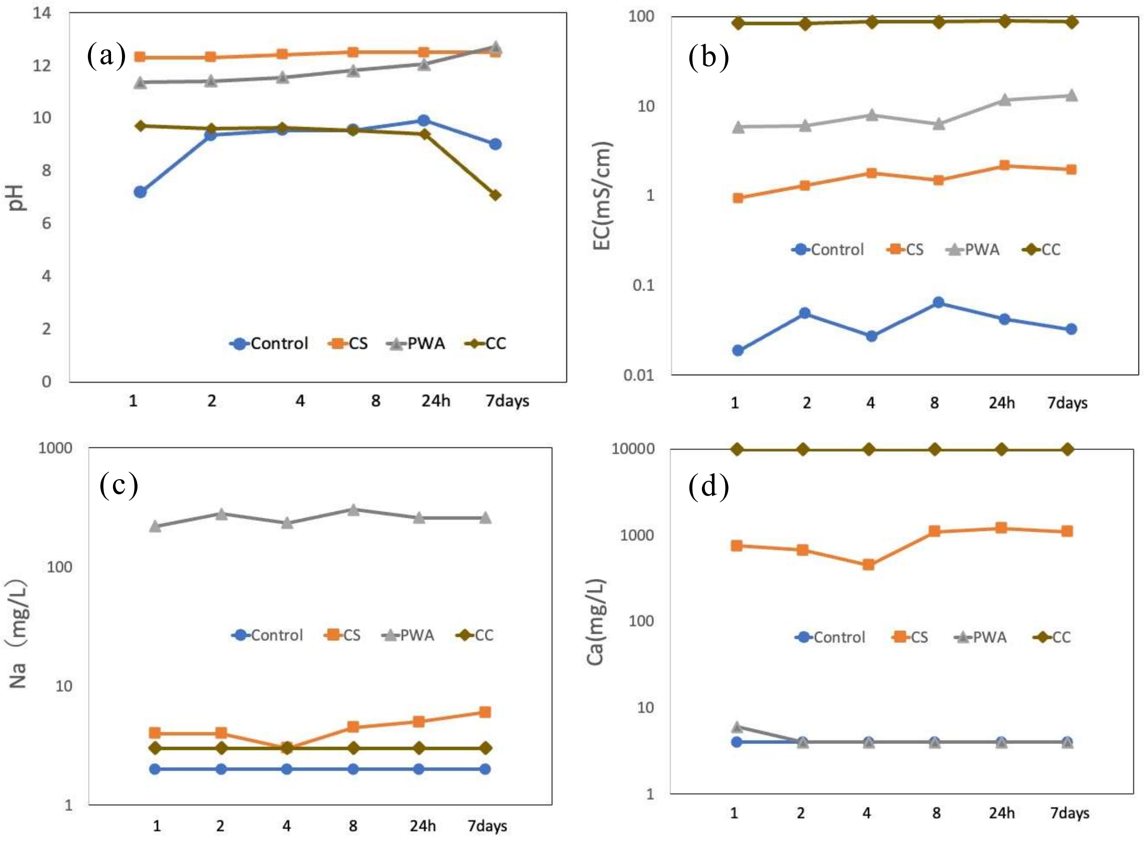


Fig.13: Changes in (a) pH, (b) EC, (c) Na and (d) Ca for different lime materials.

3.2 Ion exchange experiment

Na concentrations measured after 35 d are shown in Table 9 and Fig. 14. Based on the leaching experiments (Fig.13), we found that CC have the highest leaching of Ca concentration. Ion exchange occurs when Ca leached from the lime material exchanges with Na adsorbed on the soil particles (Fig. 7). Therefore, as the amount of uneluted concentration of Na was low, indicated that most ion exchange occurred in CC, and Na was released during the process (Fig. 14a, b, g, h). On the other hand, for CS, based on the Fig.14e and 14f, it could be observed that ion exchange occurred due to the high concentration of calcium silicate and calcium oxide. However, as compared to CC, the amount of Ca eluted from calcium silicate was relatively small, indicating the release of Na was smaller than that of CC. In addition, Ca in PWA is CaO, which should be easier to elute than calcium silicate, however, the Na eluted was the least, with approximately 10% (Fig. 14c and 14d).

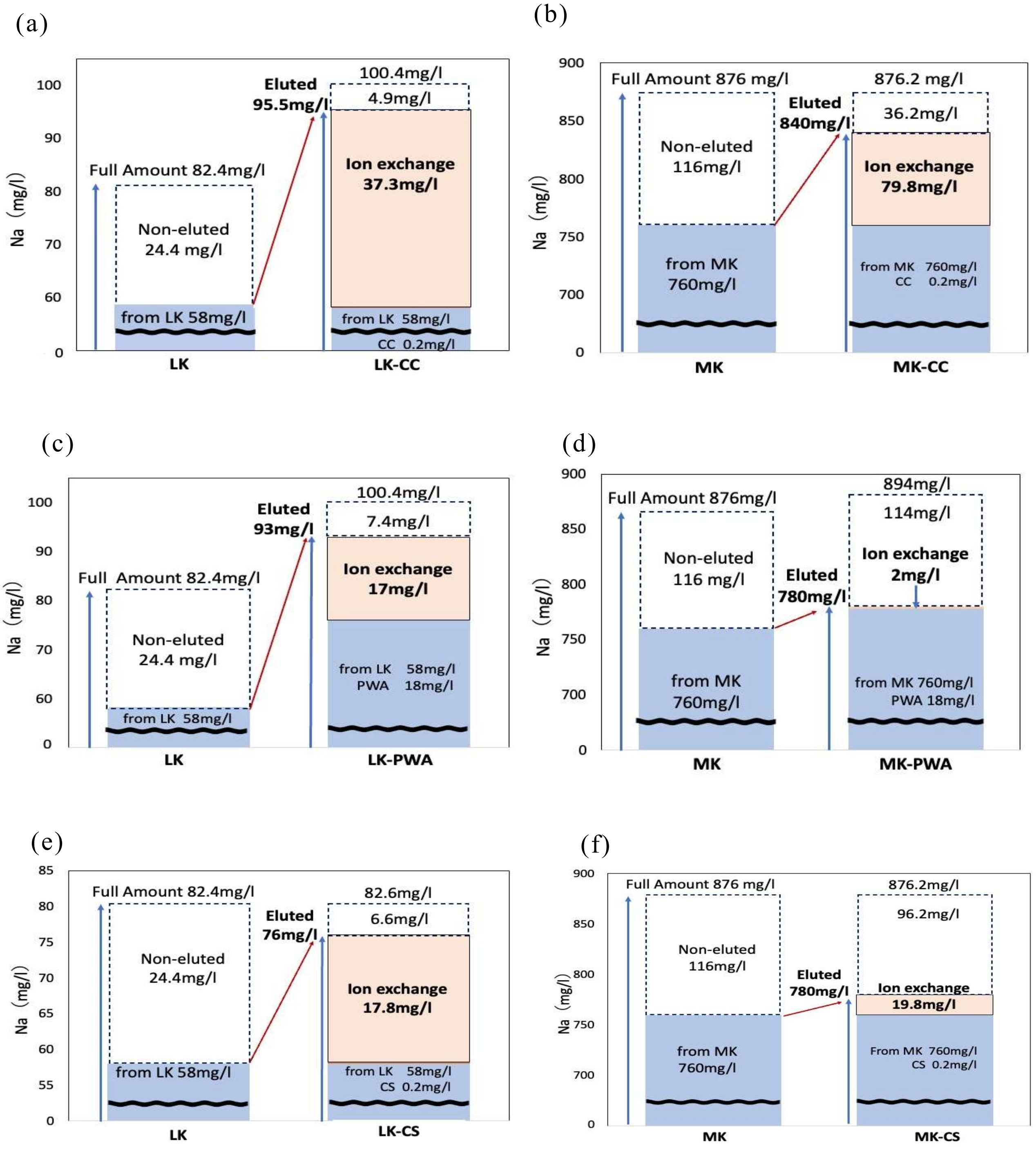


Fig.14: Comparison of sodium concentration (after 35 days) in various lime materials in salt affected soil for (a)LK and LK-CC, (b)MK and MK-CC, (c)LK and LK-PWA, (d)MK and MK-PWA, (e)LK and LK-CS, (f)MK and MK-CS, (g)LB and LB-CC, (h)MB and MB-CC, (i)LB and LB-PWA, (j)MB and MB-PWA, (k) LB and LB-CS, (l) MB and MB-CS.

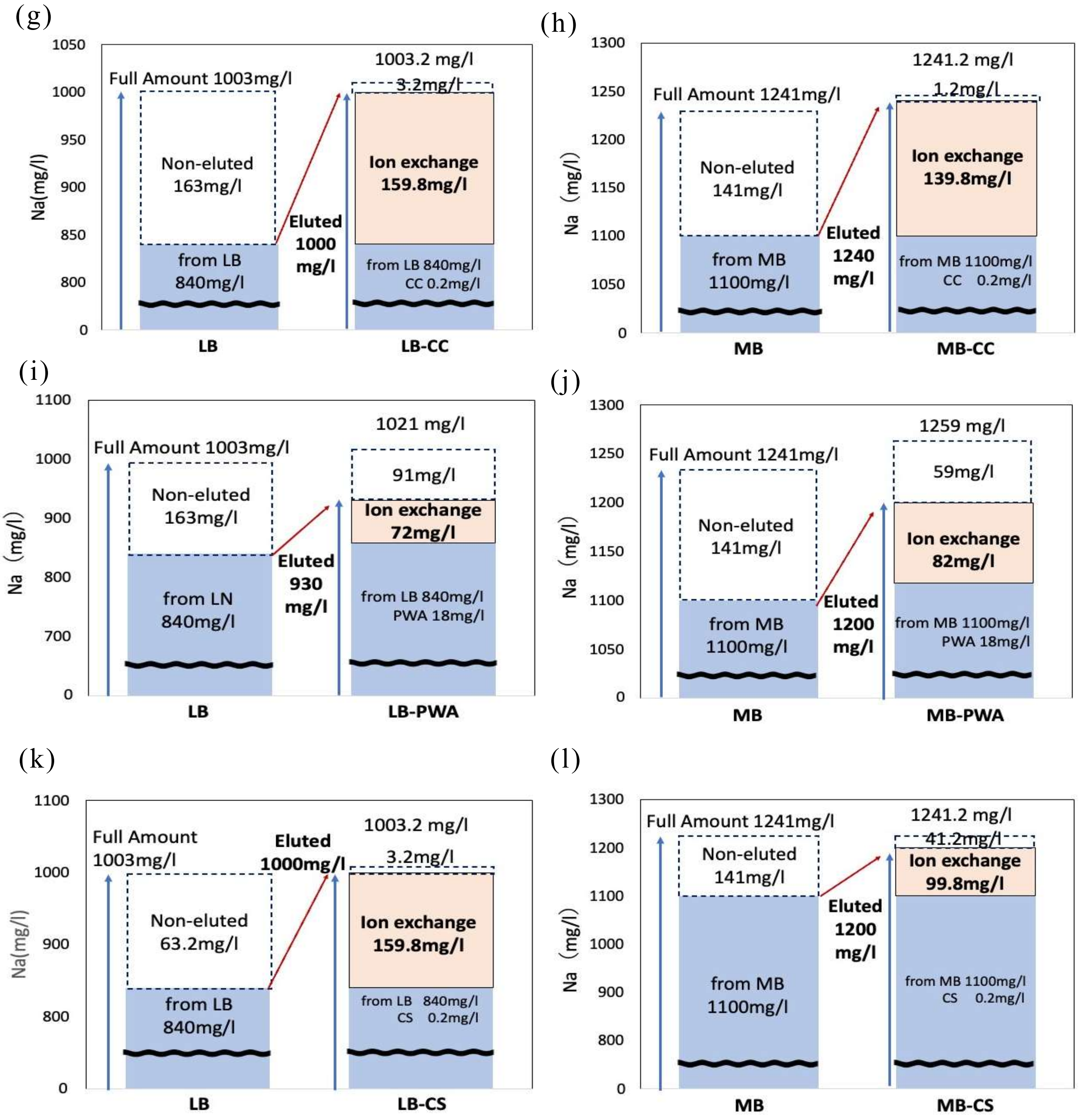


Fig.14: Comparison of sodium concentration (after 35 days) in various lime materials in salt-impacted soil (continued from the last page).

The amount of Na that leached by bentonite during ion exchange was higher than kaolinite, regardless of the type of lime material and the soil salinity. The CEC of bentonite was 80-100 mEq/100 g, greater than kaolinite's 3-15 mEq/100 g [10]. Therefore, more Ca was adsorbed, and more Na was released in bentonite as compared to kaolinite. However, both kaolinite and bentonite did not release much Na in middle salinity soils as compared to low salinity soils due to the CEC of kaolinite and bentonite. Therefore, the Na content eluted from middle salinity affected soil increased due to the adsorption capacity of a given volume of soil for adsorbing the Ca.

Table 9: Sodium concentration in water (mg/L).

<Low salinity affected soil>

Kaolinite	Eluted Na	Insoluble Na
LB-CC	840	163.0
LB-PWA	1,000	3.2
LB-CS	930	91.0
LB	1,000	3.2

Bentonite	Eluted Na	Insoluble Na
LK-CC	760	116.0
LK-PWA	840	36.2
LK-CS	780	114.0
LK	780	96.2

<Middle salinity affected soil>

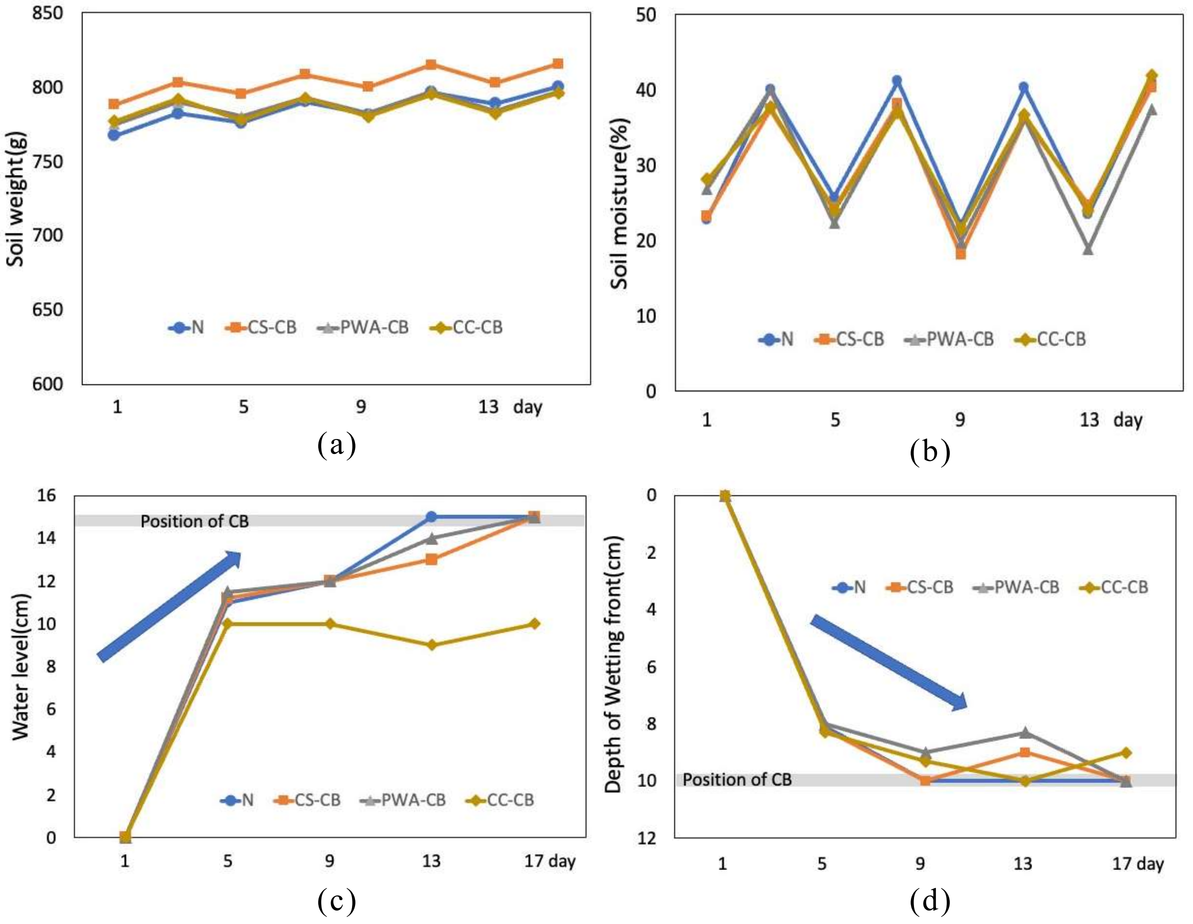
Kaolinite	Eluted Na	Insoluble Na
MB-CC	1,100	141.0
MB-PWA	1,240	1.2
MB-CS	1,200	59.0
MB	1,200	41.2

Bentonite	Eluted Na	Insoluble Na
MK-CC	58	24.4
MK-PWA	96	0
MK-CS	93	7.4
MK	76	6.6

3.3 Salinity damage control

Fig. 15 shows the changes in soil weight and surface water content before and after watering. Watering increased soil weight and surface water content. However, after 3 d, the added water evaporated, and the weight and moisture content returned to almost the original values. The location of the infiltration front (boundary between the wet and dry areas formed by watering from the soil surface) moved downward due to watering, and by the 9th day, it had almost reached the CB in all plots. However, as water evaporated, the surface layer gradually began to dry out (Fig. 16), and the infiltration front fluctuated within a range of about 2 cm (Fig. 16). This indicates that the site was able to reproduce a semi-arid environment where soil moisture fluctuates systematically due to the small amount of rainfall [11]. The groundwater level was found to rise sharply, up to a height of 12 cm from the initial position due to capillary action, and slowed down. However, in the area where calcium chloride CB was applied, although the wetting just below the CB, the water level clearly stopped at about 10 cm above the CB. In addition, as shown in the Fig.16, the soil at about 2 cm above and below the CC-CV is black and has high moisture content, indicating the water-soluble $CaCl_2$ was dissolved. The paste-like $CaCl_2$ CB dissolved by the stored water prevented evaporation of groundwater, and thus, the groundwater level did not rise.

The results of the soil analysis are shown in Table 10. The soil moisture in the 3 cm above and below the CB was about 30-40% for all plots, indicated that even though the surface layer was dry, moisture was retained around the CB. We also found that higher moisture content in the soil below the CB than above it, which might be due to the water absorbency of CBs for the rising groundwater. Furthermore, in the CC-CB, soil moisture was higher above and below the CB, due to the leaching of calcium chloride which has absorbed water. The pH was not extremely high even when lime material was used in the CB for the eluted solution as it might be adsorbed by the soil. Since many crops grow well in slightly acidic to alkaline soils; therefore, we found that the application of CB did not interfere with their cultivation.



(a) (b)

(c) (d)

Fig.15: Properties of (a) soil weight (b) surface soil moisture (c) groundwater level (d) depth of infiltration front for different CS materials.

The results of the soil analysis are shown in Table 11. The soil moisture in the 3 cm above and below the CB in was about 30-40% for all plots. This indicated that even though the surface layer was dry, moisture was retained around the CB. It was also found that higher moisture content in the soil below the CB than above it, which might be due to the water absorbency of CBs for the rising groundwater. Furthermore, in the CC-CB, soil moisture was higher above and below the CB, due to the leaching of $CaCl_2$ which has absorbed water. The pH was not extremely high even when lime material was used in the CB for the eluted solution as it might be adsorbed by the soil. Since many crops grow well in slightly acidic to alkaline soils; therefore, the application of CB was found not to interfere with their cultivation.

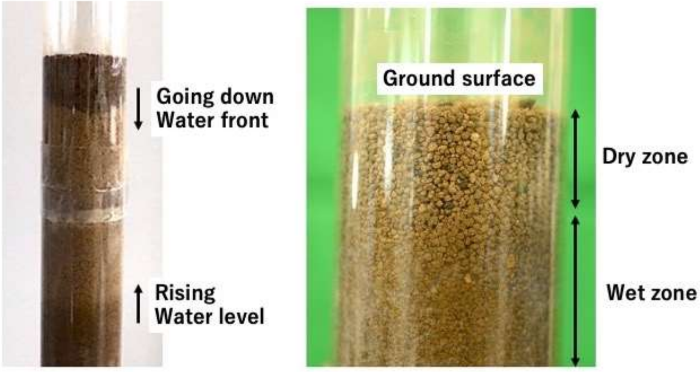


Fig.16: Soil conditions for water front and groundwater movement during wetting (left) and drying of surface layer (right).

Fig. 17: CC-CB dissolves above and below the CB.

Table 10: Soil analysis after 35 d of experiment in the salinity suppression test.

＜Topsoil＞

Experimental Plot	Soil Moisture (%)	pH	EC (mS/cm)	Ca (mg/L)	Na (mg/L)
CC-CB	71.6	5.5	0.20	36	4.0
CS-CB	32.7	5.7	0.19	15	5.0
PWA-CB	32.2	5.6	0.08	11	3.0
N	37.3	6.2	1.02	10	222

＜Soil below the CB＞

Experimental Plot	Soil Moisture (%)	pH	EC (mS/cm)	Ca (mg/L)	Na (mg/L)
CC-CB	69.4	5.5	7.93	2,300	88
CS-CB	37.3	5.6	0.86	430	170
PWA-CB	40.3	5.5	0.94	29	200
N	42.7	5.6	1.53	15	380

The EC in the surface layer was higher in the N plot without CB, with Na increased to 222 mg/L, indicating the occurrence of salinization. Na concentrations in the lower layers are also higher in N and CC-CB. The Na concentration in the soil elevated due to soil moisture. However, in CC-CB, Ca increased to 2,300 mg/L, suggesting that the higher EC in CC-CB was not caused by the replacement with Na^+, but mainly due to the Ca^{2+} from dissolved calcium chloride. The Ca concentration was the same as in the leaching experiment, with CC-CB followed by CS-CB (contains converter slag) and PWA-CB (contains a small amount of calcium oxide). The Na concentration in the lower layer was lowest in CC-CB (88 mg/L), followed by SC-CB and PWA-CB. The Ca and Na concentrations suggest that the ion exchange between them took place in the lower part of the CB due to leaching of Ca^{2+}, thereby suppressing salt accumulation. In addition, CC-CB has higher concentration Ca in the surface, so SC-CB and PWA-CB were also slightly increased. It is presumed that CB made of gravels alone can block capillary action, but the surface layer becomes hyperarid as the water cannot penetrate it, making it impossible to cultivate the crops. In this study, plant residues were mixed with CBs to deliver Ca-containing stored water under the CBs to the surface layer. This is because plant residues are expected to absorb water through the capillary action from the plant fibers. The increased in Ca concentration in the surface layer suggests that the stored water is supplying to the surface layer.

3.4 Cultivation experiment

The growth status of lettuce seedlings after 28 d planting is shown in Fig. 18. There are wilted leaves immediately after planting which might be due to insufficient water absorption. However, after 7 d, the seedlings in the area with CBs began to regrow and develop leaves. However, in the area without CBs, the leaves continued to turn yellow, and the growth was significantly delayed (Fig. 18d). Lettuce and pea are crops with extremely low salt tolerance that can be affected by an EC of less than 1.0 mS/cm. In particular, lettuce is prone to leaf senescence, a phenomenon known as tip burn due to calcium deficiency caused by hyperhidrosis or elevated sodium concentrations in the soil [12]. However, in the plots with CB, salinization was suppressed, and the CB supplied with insufficient calcium, so the damage to the plants were suppressed.

Fig. 18: Growth of lettuce after four weeks planting for (a) CC-CB, (b) CS-CB, (c) PWA-CB, (d) N

4. Conclusions

In this research, we constructed a CB which made up of low-cost easily available materials at depth of 1 cm, for addressing this issue in the arid or semi-arid regions. As results of the experiments, we observed that the salinization suppression without requiring huge amount of water. We also found that the application of gravel CB effectively prevented the capillary action of agricultural crops by dissolving Ca^{2+} in CB with the stored water, and eventually supplying the water resources to the surface layer by capillarity movement using plant residues. Furthermore, we proved that minerals such as calcium and magnesium supplied from the lime materials, are possible to suppress physiological damage that are likely to occur in dry land and salty soil. By mixing lime materials such as CC, PWA, and CS, it is possible to produce CB that is effective in both suppressing salt accumulation and promoting crop growth. In addition, the CB barrier can be easily constructed at low cost because CC is widely available, and the usage of PWA is sustainable (Fig. 17). The amount of Ca adsorbed is determined by the soil used. Therefore, this system will be effective in most middle salinity affected soils. The proposed CB has proven its practicality to pave a new path for developing a cost-effective and reliable system for solving water shortages associated with the increased food insecurity in arid and semi-arid regions.

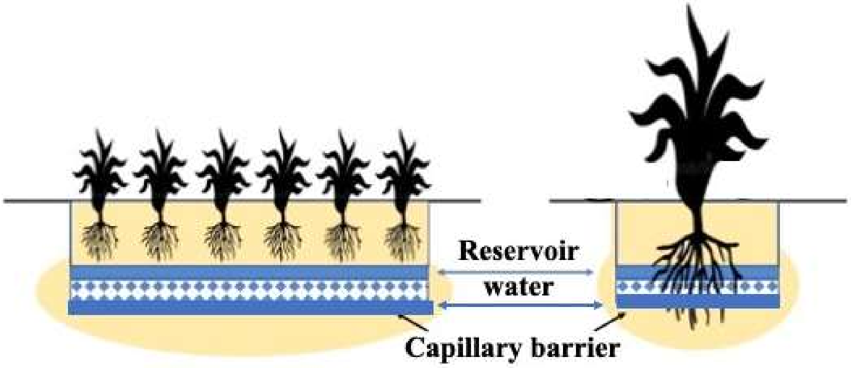


Fig.17: Application of CB for local adaptation

5. Future Perspectives

Through the application of the proposed system, the local farmers are able to control salinization issues in agricultural lands in the arid and semi-arid regions without huge operation/initial investments. The water consumption for desalination will be greatly reduced and can greatly contribute to address water shortages issues for agricultural activities and promoting sustainable agriculture for people living in these regions. We would like to continue further studies to enhance the proposed system and aiming to promote a sustainable agricultural system to be applied across the globe.

6. References

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