Is the GAC Partially Desalinated Seawater an Effective Alternative for Freshwater for Agricultural Usage?

Kanjonavo Sabud

Received August 08, 2023
Accepted September 17, 2023
Electronic access October 31, 2023

As climate change increases, the freshwater crisis intensifies and the agricultural sector is put under pressure. The intersectoral competition only increases as freshwater sources are drained out by increasing temperature and population growth. Studies, therefore, report that an alternate source of irrigation water is required to sustain and grow commercially grown plants. This study explores the concept of Partial Desalination of Salt Water (PDSW) with the GAC filtration system as a possible source of irrigation water. PDSW is a concept in which saline water is desalinated just enough to sustain and grow its targeted agricultural plant. This method optimally uses energy as no extra amount of energy is required to desalinate saline water completely. This study explores whether the GAC filtration system can effectively complete PDSW such that the germination percentage of C. *dactylon*, a common perennial grass, improves when treated with filtered water. It will also contribute to the existing knowledge on the desalination of salt and brackish water through the concept of PDSW. Batches of C. *dactylon* were grown under salt stresses of 0, 12, 24, 36, 48, and GAC-filtered 48 ds/m saline concentrated solution. The results showed that the germination percentage of the GAC-filtered 48 ds/m solution plants did not significantly differ from the germination percentage of the unfiltered 48 ds/m solution plants. PDSW as a concept still needs to be explored with other setups of filtration systems. However, the GAC filtration system, on its own, has proven to be incapable of desalinating saline water such that a significant improvement in the germination percentage of C. *dactylon* occurs. The results of this paper have helped us determine if the GAC filtration is a plausible choice for PDSW of saline water.

Introduction

Climate change, the gradual increase of global temperature, has many drastic and harmful effects on the environment. One of these effects is freshwater shortages. Increasing global temperature increases the rate of evaporation, ultimately resulting in a reduction of streamflow. This will decrease the amount of freshwater available for its various uses in the domestic, agricultural, and industrial sectors. Hydrological extremes are also expected to increase[1–3], leading to decreased precipitation rates, consequently leading to even severe droughts[4–6]. In addition to the reduction in available fresh drinking water, intense droughts also affect agriculture as the necessary amount of freshwater will not be available to irrigate crops.

In addition to this, the irrigational agricultural sector is not only put under pressure by water shortages but also by increased food demands. The world population and its complementary demand for food are expected to greatly increase by 2050[7]. As agriculture grows to provide for this increased food demands, the global water demand grows with it. This development of irrigated agriculture to accommodate for increased food demand is also the main driver behind freshwater use. However, water usage for irrigation purposes is being questioned as intersectoral competition for water intensifies and water scarcity increases[6]. Intersectoral competition is the existing competition for resources between sectors of work such as energy, domestic, agriculture, etc. The demand for freshwater resources between the domestic and agricultural sectors is a good example of this type of competition. In this case, the domestic sector is obviously more prioritized, leading to more fresh water being allocated to the domestic sector at the expense of agriculture[8]. Further, as the impacts of climate change continue to intensify, water shortages will worsen due to rising sea levels and increased global temperature, mainly in the arid and semi-arid regions[9]. This will result in more intersectoral competition for freshwater sources. Therefore, in order to meet the water requirements of irrigated agriculture in parts where conventional water sources are insufficient, it has become necessary to explore new potential water sources outside of what is already available from the hydrological cycle[10].

Desalinated seawater (DSW) and brackish water desalination are the most popular methods to increase the water supply[11]. DSW has the potential to be drought-proof and an abundant water source and can be used to meet the agricultural demands in water-scarce regions[12]. Due to these characteristics, DSW is becoming a very popular alternative to freshwater. DSW, which is most often used as a supplementary source for crop irrigation due to its poorer water quality, is now also being used for direct irrigation in some arid regions where desalination is the only option for supplying agriculture[13,14].

One desalination method is the reverse osmosis (RO) desalination system which has lower energy costs when compared to other thermal desalination methods[15]. This makes the RO desalination system favored by the industrial sector. However, complete seawater desalination has high costs[16]. The RO purification method has other problems when used for agricultural purposes. The RO method has surfaced concern for the lack of plant nutrients in the filtered water as well as the accumulation of sodium in the soil[17,18]. The RO method also produces a great quantity of greenhouse gasses, producing high emissions and increasing climate change[19]. As exacerbating climate change will only serve to intensify the water shortage crisis, the RO purification method may not be the most suitable way of desalinating SW.

Another desalination method is pure distillation. Pure distillation is the process during which a liquid is heated to a boiling point in order to vaporize it, then condensed back into a liquid so that it is separated from impurities or other solutes. In the case of desalination, the salt (NaCl) impurity is separated from the water providing us with fresh water. Some of the distillation methods used for desalination include multi-stage flash (MSF), and multiple-effect distillation (MED). MED operates by utilizing a series of chambers or "effects," each at progressively lower pressures, where seawater is heated and condensed in a cascading fashion, with the heat released during condensation aiding subsequent stages. This makes MED an energy-efficient option, suitable for utilizing waste heat or solar energy. In contrast, MSF operates by repeatedly flashing seawater at different pressure levels, creating vapor that is then condensed to produce fresh water. MSF is renowned for its reliability and high freshwater output but is generally more energy-intensive than MED due to its continuous flashing process[20]. Nonetheless, both methods incur huge energy costs as well as concern for the disposal of the salt-concentrated solution or brine water. They also incur higher energy costs relative to the RO filtration system[20].

The ceramic porous membrane filtration system used in Membrane Distillation (MD) is also another way of desalinating water. MD uses a semipermeable membrane to separate a hot, pressurized liquid from a cooler liquid, which causes the volatile components of the hot liquid to vaporize and pass through the membrane, leaving behind impurities and non-volatile substances. A ceramic porous membrane is a type of filtration membrane made from ceramic materials with a porous structure. It is designed to allow the passage of certain substances while blocking others based on their size and chemical properties. A review by Arumugham et al. of the application of ceramic porous membranes for wastewater filtration and desalination noted that Hydrophobic ceramic membranes could effectively perform MD and desalinate salt water[21] Different types of ceramic membranes were explored in this study and it is agreed that lower thermal conductive membranes are better candidates for MD. However, the energy problem remains an issue in this method as it is yet another Distillation process. Albeit, it is a promising alternative to RO and pure distillation which are more energy-intensive[22].

The granular activated carbon (GAC) purification method may be a viable alternative to the RO and Distillation purification system when used for irrigation purposes. The GAC filtration system is an absorptive filtration system that uses activated carbons to catch or remove impurities from the passing solution. In this system, absorbents attract the contaminants (absorbate) from the passing solution and physically attach them to their surfaces. By physically catching contaminants, the GAC filtration system is able to purify the solution. This filtration system mainly removes organic chemicals usually responsible for objectionable odors. Recent studies have shown that the GAC filtration system, coupled with ultrafiltration, another type of molecular filtration system, can be used as a pretreatment to RO desalination of seawater to reduce RO biofouling potential (Monnot et al., 2016; Naidu et al., 2013). The GAC filtration system has a low NaCl rejection rate of 12.24% when the activated carbon membrane sieve has 3586.6 ppm of activated carbon and an electric potential of 1.2 volts. Therefore it is also possible to couple activated carbon with membrane units in industrial and water treatment plants for more effective treatment and biofouling protection[23]. One advantage of the GAC filter is its efficient removal of organic compounds, making it a top choice for reducing bio-fouling as shown by the examples. However, it has limited capability in filtering inorganic substances like salt. Nevertheless, a standout feature distinguishing the GAC filtration system from others such as RO, Distillation, and MSF is its remarkable energy efficiency, relying solely on liquid flow for the filtration process.

Studies of water filtration systems rely on robust species of plants to assess the impacts of reduced water purity on plant growth and health. C. *dactylon*, a common grass in the tropical and subtropical regions of the world, was chosen as the test plant for its salt tolerance and fast germination rate. C. *dactylon*, commonly known as Bermuda Grass, is a perennial and C4 grass. It is mainly used as turfgrass but is also considered an invasive species in agricultural areas[24]. Bermuda Grass can be used to revegetate salt-contaminated soil[25]. This can also help the agricultural sector turn sodic soil into soil able to provide enough nutrients for agricultural usage. This grass is also moderately salt tolerant with 50% shoot growth reduction reported at 24 and 33 dsm (15.36 and 21.12 g per liter)[26]. Bermuda grass is also one of the fastest-growing plants[27]. Due to the limited time scale of this research, a fast-growing test plant was needed. Bermuda grass, therefore, was chosen due to its fast growth speed. Bermuda grass can also grow in any soil type ranging from sand to clay[28]. Due to the limited restriction of soil type to alluvial soil, bermuda grass was ideal in this sense as well.

This study explores the concept of partially desalinated seawater (PDSW). In theory, when a plant is treated with PDSW, the plant is able to survive and adequately grow such that it produces its necessary agricultural product. This method uses the minimum amount of energy used to partially desalinate seawater such that it can be used for agricultural purposes. For PDSW to be a viable alternative to freshwater, PDSW has to sustain its targeted plant to a normal or near-normal growth rate. This depends on the filtration system used to obtain PDSW. This study explores whether the GAC filtration system is a viable method of obtaining PDSW by testing the filtered water's effect on batches of C. *dactylon*.

Results

The germination percentage of C. *dactylon* was recorded at different levels of salt concentrations. The increment of salt concentration resulted in the decline of the germination percentage of the C. *dactylon* plants as summarized in Figure 1.

The germination percentage of each trial per level is shown in Table 1 with each level's average given in Table 2. The standard deviation of each level is given in Table 2 as well. It is important to note that the average germination percentage of C. *dactylon* plants and the standard deviation of the unfiltered 48 ds/m solution and GAC-filtered 48 ds/m solution was the same at 0% germination rate and 0 SD.

ds/m(g/L)	Trial 1	Trial 2	Trial 3
0(0)	86.67%	90%	83.33%
12(7.68)	43.33%	46.67%	53.33%
24(15.68)	10%	6.67%	16.67%
36(21.24)	6.67%	3.33%	0%
48(30.06)	0%	0%	0%

Table 1

	T1	T2	T3
GAC	0%	0%	0%

The results from the One Way ANOVA test on the control study is shown in supplementary information as Figure 1. The results from the One-way ANOVA test on the GAC filtration study are shown in supplementary information as Figure 2.

The p-value comparing the variance between the salinity levels in the control group is 3.34E-10 which is less than our chosen alpha value of 0.05. This goes to show that there is a major significant difference between the control groups of this study. This difference can be visually seen in Figure 6. Figure 6 displays the germination percentage of each salinity level. The error bars of each salinity level are also displayed. As it can be seen from Figure 6, the difference between the germination percentage of the 0, 12, and 24 ds/m salinity concentration was significant because their error bars did not overlap. However, the difference between 24, 36, and 48 ds/m salinity concentration was not significant because their error bars overlapped.

ds/m(g/L)	AVG	SD
0(0)	86.67%	2.7189
12(7.68)	47.67%	4.1581
24(15.68)	11.1133%	4.1576
36(21.24)	3.33%	2.7230
48(30.06)	0%	0

Table 2

	AVG	SD
GAC	0%	0

There was no significant difference between the GAC-treated 48 ds/m solution and the unfiltered 48 ds/m solution. There was no p-value comparing the GAC-treated 48 ds/m solution and the unfiltered 48 ds/m solution. This is because there is no variation in either group. The average and the standard deviation of both groups are 0. As there is no variation and no differences between the data between groups, there is also no significant difference between groups. This shows that the GAC filter does not partially desalinate seawater so the germination percentage of C. *dactylon* improves.

Discussion

The need for an alternative to freshwater for agricultural use is imminent due to water shortages and the prioritization of domestic water usage over agriculture[8]. Therefore, the desalination of sea and brackish water among other alternatives is being entertained as a possible alternative for freshwater. However, complete desalination of seawater has high energy costs[19,29]. Therefore, a search for a more energy-efficient system of desalination is still ongoing. Partially desalinated seawater (PDSW), the main focus of this paper, may be the answer to the desalination problem. PDSW is obtained by partially desalinating seawater using less energy. PDSW can then be used for irrigation agriculture. However, for PDSW to be considered a viable alternative to freshwater, PDSW has to sustain its intended agricultural product to normal or near-normal growth measures. This depends on the filtration system used to obtain PDSW.

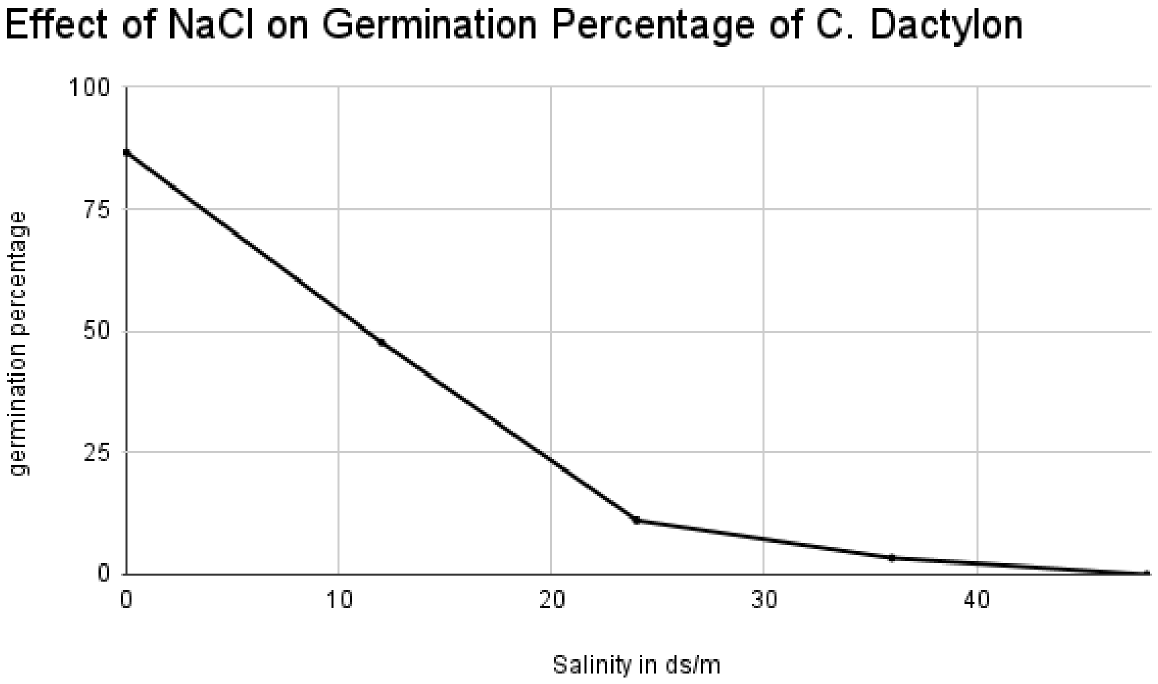


Fig. 1 As the salinity concentration increases, the percent germinated of C. *dactylon* decreases

The GAC filtration system was used to filter saline water to see if it was a viable option for the use of obtaining PDSW. The GAC filtration system has a great affinity for filtering organic molecules and has been used as a pretreatment to the main desalination units such as the RO filtration system. This has helped lower the biofouling potential of the RO units[30,31]. However, the GAC's ability to capture salt still remains to be seen. A study reports that the highest salt rejection rate obtained was 12.24% when there were 3586.9 ppm of GAC and an electric potential of 1.2 V[23]. This study also explores whether the GAC is able to desalinate saline water enough to obtain a significant difference in the germination percentage of C. *dactylon*, the test plant used in this study. The desalinated water obtained from the GAC filter was then used to water batches of C. *dactylon* and the effect of the filtered water on the germination percentage of C. *dactylon* was observed. C. *dactylon* was chosen as the test plant for its high germination rate as well as its high salt tolerance[26]. Due to C. *dactylon*'s high salt tolerance, we were able to provide an additional threshold of whether the GAC filter could at least desalinate salt water enough to make a significant difference in the germination rate of a highly salt-tolerant plant.

The germination percentages of the different salt concentration levels showed an exponential decay. This can be seen from Table 3 which shows linear, logarithmic, and exponential models fitted on the data and their respective R2 values. The R2 or R-squared value is a statistical measurement of how correlated to curves are. A higher R2 value signified a greater fit. As shown by Table 3, the exponential curve's R2 of 0.969 is the highest among the linear and logarithmic curves. This shows that the data curve of germination percentage against salt concentration is similar to an exponential curve. Another study by Zhang et al[32]. also conducted a similar experiment by measuring germination rate against salt stress. Even though the species of the grass were different, their findings demonstrated a similar pattern observed in this study (Zhang et al. 2012)[32]. However, the germination percentages of C. *dactylon* acquired at different salt concentrations in this study were different from the ones previously acquired in an earlier study. A study conducted by Mahmood et al[33] explored the salt tolerance of different plants growing on saline soil by measuring their germination percentage. C. *dactylon* was one of the tested plants and the germination percentages at different salt concentrations were measured. In this study, the germination percentages of C. *dactylon* reached 0% at only 20 ds/m saline concentration (Mahmood et al. 1996)[33], while in this study, the first occurrence of 0% was at the salinity level of 36 ds/m. This inconsistency may have been caused by dif-

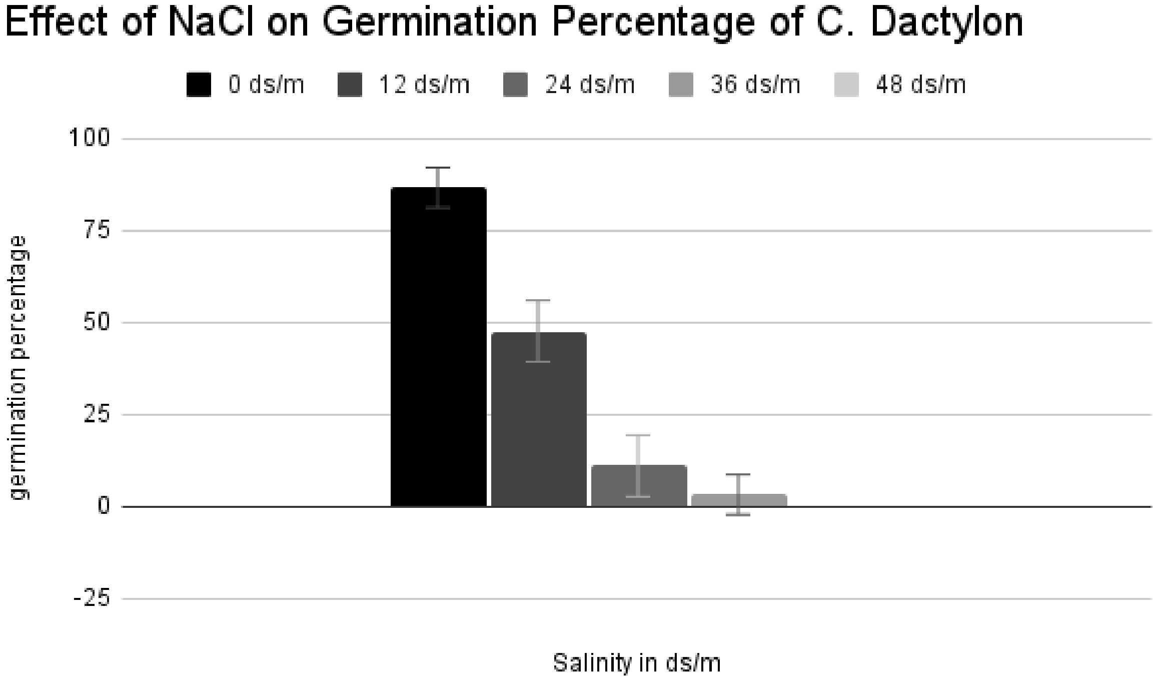


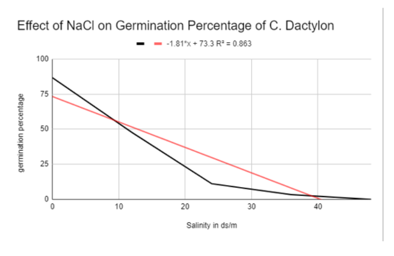
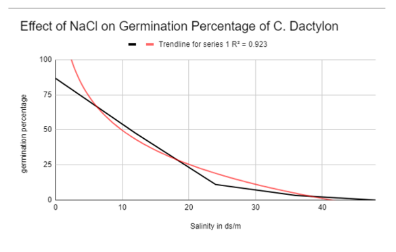
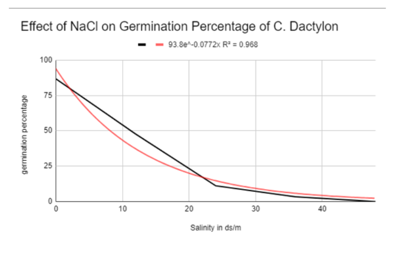
Fig. 2 Graphical display of germination percentage over the control study's salinity levels of 0, 12, 24, 36, 48 ds/m

ferent watering routines and the different soil types used to grow the plants. Mahmood et al also maintained soil moisture levels which was not done in this study. Mahmood et al[33]. itself reported that an increase in soil moisture related to an increase in germination percentage. Therefore, differences in soil moisture, watering routines, and soil type may be the reason behind the observed germination percentage differences. Nevertheless, the effects of these variables remain a topic of inquiry for future study.

The results comparing the effect the GAC filtration system had on the germination percent of C. *dactylon* to the unfiltered water's effect showed that the GAC filter does not sufficiently desalinate saline water to make a significant difference in the germination rate of C. *dactylon*. This findings was supported by the existing literature and a general consensus that GAC filters mainly filter organic by the method of absorption[30,31]. The GAC filter is made of heated or activated carbons which are spread over and indented to create the most surface area. This allows the filter to have the most contact with its passing solution. The GAC filter is able to filter organic compounds by creating carbon to carbon bonds which enable the filter to 'absorb' organic contaminants. However, salt (NaCl) is an inorganic compound. Therefore, the GAC filter is not the ideal filter for desalinating water. This signifies that the GAC filtration system, on its own, is not a viable option for the use of obtaining PDSW as it does not sustain a salt-tolerant plant with its filtered water. For future studies, quantitative measurements on the extent of desalination done by the GAC filter also needs to be made. This will help us determine the potential of the GAC filtration system for desalinate purposes. Nonetheless, PDSW as a concept still needs to be explored more intensively with different combinations of filtration systems. The reason behind PDSW is to reduce energy costs by only partially desalinating sea water. Therefore, filtration combinations such as partial distillation or ceramic membrane filtration systems in the context of PDSW still need to be explored in future studies.

Even though the GAC filtration system is not a viable option, other desalination systems such as the ceramic porous membrane filtration system, and the RO filtration system can possibly obtain PDSW through controlled desalination. The ceramic porous membrane filtration system is another membrane filtration system that uses an absorptive filtration method similar to a GAC filter. Similar to this study, future studies in the desalination field can explore the use of the ceramic porous membrane filtration system to obtain PDSW. Future studies can also explore how the RO filtration system can effectively partially desalinate seawater such that the de-

Table: 03 Linear, Logarithmic, and Exponential fit model and their respective R^2 values.

<table>
<tr><td>Linear</td><td>Logarithmic</td><td>Exponential</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>$R^2 = 0.863$</td><td>$R^2 = 0.923$</td><td>$R^2 = 0.969$</td></tr>
</table>

salinated water is able to sustain agricultural products. This would require controlled desalination, another very interesting method of desalination, as the RO filtration system is typically used for complete desalination. Controlled or partial desalination will conserve energy and help reduce the rate of climate change as well as provide an alternative to freshwater usage in the agricultural sector.

Conclusion

This study attempted to understand the effects of Partially Desalinated Salt Water (PDSW) on the germination rate of a C. *dactylon*. The GAC filtration system was used to obtain PDSW. However, whether the GAC filtration system can partially desalinate salt water to the necessary salt level for the optimal growth of C. *dactylon* still remains to be seen. The results demonstrated that the GAC filter does not sufficiently desalinate salt water to make a significant difference in the germination rate of C. *dactylon*, a highly salt-tolerant plant[26]. This shows that the GAC filter is not a viable choice for obtaining PDSW, a possible alternative for freshwater. Even though this study invalidates the GAC filter as a possible option for obtaining PDSW best for C. *dactylon*, PDSW as a concept still remains to be explored more extensively. The primary objective behind PDSW is to mitigate energy expenses by partially desalinating seawater. Consequently, it is essential to investigate filtration approaches like partial distillation or ceramic membrane filtration systems within the framework of PDSW in forthcoming research endeavors. Therefore, PDSW remains a viable solution to the freshwater crisis in the agricultural sector. Surprisingly, the results obtained from the positive control part of the experiment did not align completely with the results of a study previously conducted by Mahmood et al[33]. Even though both the results followed the same trend, this study's germination percentages first reached 0% when treated with the 36 ds/m saline water but in Mahmood's study, they first reached 0% when treated with the 20 ds/m saline water. This discrepancy may have been caused by a different growing routine or maybe even soil type. Either way, it remains a topic of inquiry for future studies.

Methods

There were two parts to this study. The first part consisted of observing the effect of different salt concentration solutions on the germination percentages of C. *dactylon*. This part acted as a positive control for the study. The second part consisted of the growing batches of C. *dactylon* under the GAC filtered water solution. Due to material restrictions, only the most salt concentrated water solution used in the control experiment was filtered and used in the second part. The results were then compared to the results of the most salt concentrated level in the control experiment.

In summary, this study treats C. *dactylon* with 0, 7.68, 15.68, 21.24, and 30.06 grams per liter of NaCl and water solution (0, 12, 24, 36, 48 ds/m[34] and observes their germination rate in order to acquire the benchmark germination rate of each NaCl concentration. Then the GAC filtration system is used to treat the 30.06 g per liter solution and the treated water is used to water the C. *dactylon* plants. Then the germination percentage of the C. *dactylon* plants when watered with the GAC filtered 30.06 g per liter water is compared with the germination percentage of the C. *dactylon* plants watered with non filtered 30.06 g per liter water.

Control Study

Plastic containers (18.00 x 13.00 x 4.50) were filled, leaving 0.5 cm from the top, with alluvial soil. Two small holes with a radius of 1 cm were cut on opposite sides of the container to allow for water drainage. Indents were made of 0.5 cm depth in the soil for each container. The indents formed a table consisting of 5 rows and 4 columns; each indent was equally spaced from others by a measure of 3 cm. Fifteen grams of C. *dactylon* were randomly and equally separated into 30 different units; each containing 0.5 gram of seeds. These units were then randomly placed in each indent previously made and then were covered by loose soil. The rows and columns were marked by toothpicks on the margins of the container to help identify and number each seed unit.

A spray bottle was used to water the seeds to reduce soil disturbance. The seeds were watered with 100 ml of their respective salt concentrated salt water solution at a regular interval of 3 days. In the second week, the number of successful germination events was counted and the germination rate was calculated.

Creating Salt Level

Using the conversion factor of 640 mg per liter being equal to approximately 1 ds m-1 (M. C. Shannon et al., n.d.), Salt concentration levels of 0, 12, 24, 36 and 48 ds m-1 were created by mixing 0, 7.68, 15.36, 23.04 and 30.064 grams of salt, respectively, with a liter of normal tap water. The salt was transferred to a 1 liter container filled with control water after it was weighted using an electric scale. The salt in the water containers was then dissolved by stirring.

GAC Desalination Study

A granular activated carbon filtration system (GAC), was used to filter the highest level of salt concentrated salt water solution. In this case, the 48 ds m-1 salt water solution was passed through the GAC filtration system and the filtered water was collected. Figure 3 shows the GAC filter configuration while treating the saline water with the GAC filter. The commercially used GAC filter used in this study consisted of zeolite, wheat rice stone, calcium sulfite, and natural coconut shell activated carbon in that order. These 4 materials were encapsulated by a layer of PVA non-woven fabric. Figure 4 shows the components of the specific GAC filter.

The volume of the filtered water was recorded to check for any water loss. Containers with C. *dactylon* seeds were prepared via the same methods used in the Comparative Study. The filtered water from the GAC system was then used to treat their respective batches of C. *dactylon* seeds. The same methods used in Experiment 1 for watering the seeds was used in this Experiment as well. After week 1 and 2, the percent of seeds germinated, height, color, and leaf count was recorded for both levels.

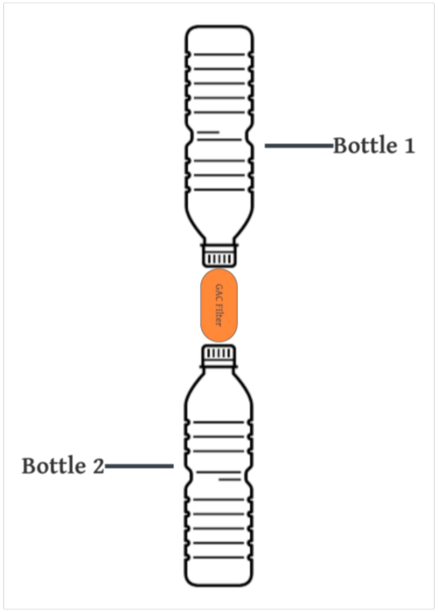


Fig. 3 Demonstrates the configuration used while treating the saline water with the GAC filtration system. Container 1 contains the pre-treatment water and container 2 contains the treated water.

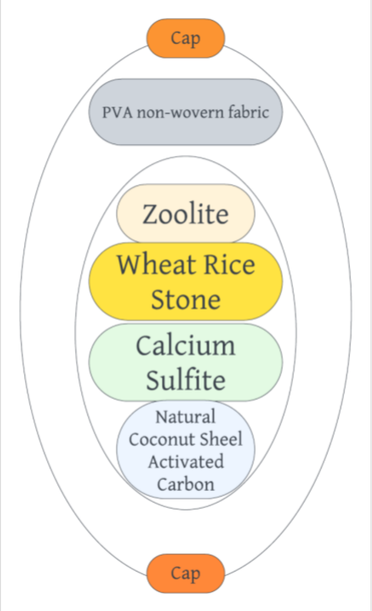
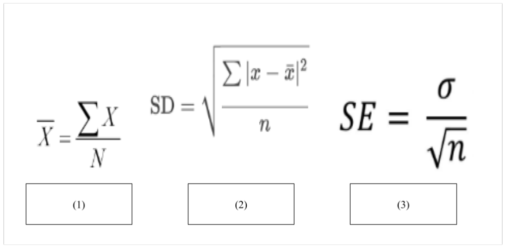


Fig. 4 Shows the individual components of the specific GAC filter used in this experiment.

Statistical Analysis

A One-Way ANOVA Test was used to determine if there was any significant difference between the control groups and another One Way ANOVA Test was used to determine if there was any significant difference between the 48 ds/m unfiltered saline water group and the GAC filtered water group. A p-value of 0.05 was used to determine significance.

In addition to a One-way ANOVA Test, a basic bar graph consisting of the averages and the standard error bars for each level was created. The averages (1), standard deviations (2), and the standard error (3) confidence intervals of all levels were obtained using the formulas given below in Figure 5.



$$\bar{X} = \frac{\sum X}{N} \qquad \text{SD} = \sqrt{\frac{\sum |x - \bar{x}|^2}{n}} \qquad SE = \frac{\sigma}{\sqrt{n}}$$

(1) (2) (3)

Fig. 5 Formulaic descriptions of the statistical tools used. (1) Shows the Standard deviation formula, where $\bar{X}$ is the average, X is the individual data values, and N is the number of data values. (2) Shows the average formula where $\bar{X}$ is the average, X is the data value, and N is the number of data values. (3) Shows the Standard Error formula. Here σ is the SD and n is the sample size.

The bar graph was used for visual help as well as to check the significance between groups. As the ANOVA test only identified the entire data, not groups, being significant or not, this visual test helped us determine the significant differences between levels.

References

1 R. Foti, J. Ramirez and T. Brown, *Climatic Change*, **125**, 413–427.

2 G. Leng, M. Huang, N. Voisin, X. Zhang, G. Asrar and L. Leung, *Environmental Research Letters*, **11**, 114003.

3 B. Naz, S.-C. Kao, M. Ashfaq, D. Rastogi, R. Mei and L. Bowling, *Global and Planetary Change*, **143**, 100–117.

4 B. Cook, J. Smerdon, R. Seager and S. Coats, *Climate Dynamics*, **43**, 2607–2627.

5 A. Dai, *Nature Climate Change*, **3**, 52–58.

6 U.S.G.C.R.P., *Climate Science Special Report*.

7 J. Foley, N. Ramankutty, K. Brauman, E. Cassidy, J. Gerber, M. Johnson and D. Zaks, *Nature*, **478**, year.

8 M. Qadir, B. Sharma, A. Bruggeman, R. Choukr-Allah and F. Karajeh, *Agricultural Water Management*, **87**, 2–22.

9 S. Shahid, M. Zaman and L. Heng, *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*, Springer International Publishing, p. 43–53.

10 O. Barron, R. Ali, G. Hodgson, D. Smith, E. Qureshi, D. McFarlane, E. Campos and D. Zarzo, *Desalination*, **364**, 33–45.

11 M. Shannon, P. Bohn, M. Elimelech, J. Georgiadis, B. Mariñas and A. Mayes, *Nature*, **452**, 301–310.

12 M. Elimelech and W. Phillip, *Science*, **333**, 712–717.

13 F. Díaz, M. Tejedor, C. Jiménez, S. Grattan, M. Dorta and J. Hernández, *Agricultural Water Management*, **116**, 62–72.

14 G. Medeazza, *Desalination*, **169**, 287–301.

15 L. Greenlee, D. Lawler, B. Freeman, B. Marrot and P. Moulin, *Water Research*, **43**, 2317–2348.

16 M.-G. Martínez-Alvarez and Soto-García, *Seawater desalination for crop irrigation—A review of current experiences and revealed key issues*, `https://www.sciencedirect.com/science/article/pii/S001191641530134X`.

17 A. Ben-Gal, U. Yermiyahu and S. Cohen, *Journal of Environmental Quality*, **38**, 529–536.

18 U. Mandal, A. Bhardwaj, D. Warrington, D. Goldstein, A. Bar Tal and G. Levy, *Geoderma*, **144**, 509–516.

19 B. Martin-Gorriz, M. Soto-García and V. Martínez-Alvarez, *Energy*, **77**, 478–488.

20 N. Wade, *Desalination*, **136**, 3–12.

21 T. Arumugham, N. Kaleekkal, S. Gopal, J. Nambikkattu, K. Rambabu, A. Aboulella, S. Wickramasinghe and F. Banat, *Journal of Environmental Management*, **293**, 112925.

22 P. López-Porfiri, S. Ramos-Paredes, P. Nuñez and P. Gorgojo, *Npj Clean Water*, **6**, year.

23 Maddah, *Journal of Applied Science and Engineering Methodologies*.

24 L. Holm, D. Plucknett, J. Pancho and J. Herberger, *How to access research remotely*, `https://www.cabdirect.org/cabdirect/abstract/19782319336`, Retrieved August 8, 2022, from.

25 K. Singh, V. Pandey and R. Singh, *Ecological Engineering*, **54**, 32–38.

26 M. Uddin and A. Juraimi, *TheScientificWorldJournal*, 409413.

27 C. Leto, S. Bella, T. Tuttolomondo, G. Virga, M. Volterrani, S. Magni, M. Gaetani, N. Ntoulas and L. Caturegli, *Acta Agriculturae Scandinavica Section B-soil and Plant Science*, **64**, 722–733.

28 Bermudagrass, *CALS*, `https://cals.cornell.edu/weed-science/weed-profiles/bermudagrass`.

29 R. Semiat, *Environmental Science Technology*, **42**, 8193–8201.

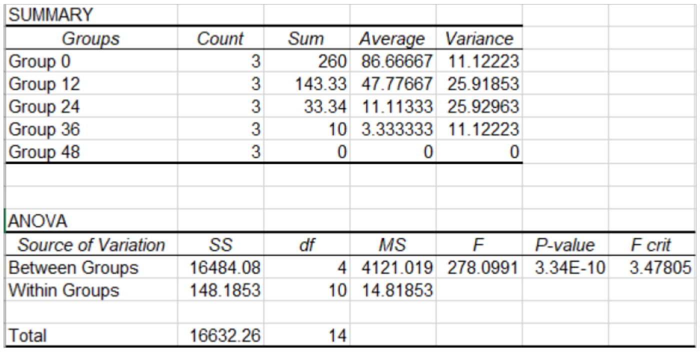
30 M. Monnot, S. Laborie and C. Cabassud, *Desalination*, **383**, 1–11.

31 G. Naidu, S. Jeong, S. Vigneswaran and S. Rice, *Desalination*, **309**, 254–260.

32 Q. Zhang, K. Rue and S. Wang, *HortScience horts*, **47**, 527–530.

33 K. Mahmood, K. Malik, M. K. Lodhi and K. H. Sheikh, *Biologia Plantarum*, **38**, year.

34 M. Shannon, J. Rhoades and J. Draper, *Assessment of salt tolerance in rice cultivars in response to salinity problems in California*, `https://doi.org/10.2135/cropsci1998.0011183X003800020021x`.



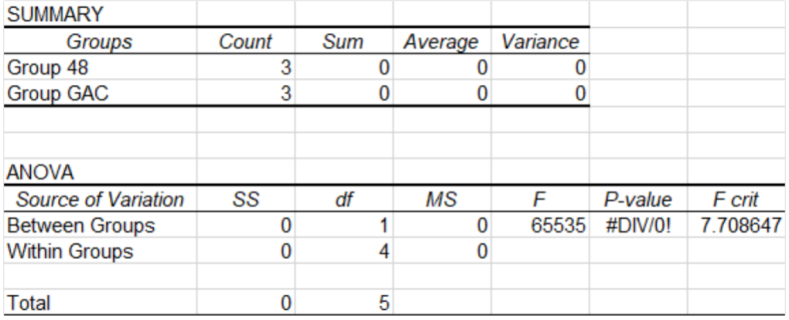
SUMMARY

Groups	Count	Sum	Average	Variance
Group 0	3	260	86.66667	11.12223
Group 12	3	143.33	47.77667	25.91853
Group 24	3	33.34	11.11333	25.92963
Group 36	3	10	3.333333	11.12223
Group 48	3	0	0	0

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16484.08	4	4121.019	278.0991	3.34E-10	3.47805
Within Groups	148.1853	10	14.81853			
Total	16632.26	14				

Fig. 6 Supplementary Image: One-way ANOVA Test between control groups



SUMMARY

Groups	Count	Sum	Average	Variance
Group 48	3	0	0	0
Group GAC	3	0	0	0

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	1	0	65535	#DIV/0!	7.708647
Within Groups	0	4	0			
Total	0	5				

Fig. 7 Supplementary Image: One-way ANOVA Test between the 48 ds/m control group and the GAC-filtered solution group