



## Increasing crop productivity using a porous $\alpha$ amendment in sandy soil

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### Abstract

The objective of this study was to determine the effects of a porous $\alpha$  amendment (recycled from used glass bottles) on water holding capacity, crop growth and nutrient availability in a sandy soil assessed by growing Swiss chard (*Beta vulgaris* L.). Treatments consisted of two porous $\alpha$  layers of 2 and 5 cm thickness placed in the soil. The control soil received no treatment. The experiment was conducted and replicated five times in a sandy field under a greenhouse. A leaching experiment was conducted in a laboratory. The results show the placement of a porous $\alpha$  material substantially increased the yield as compared to the yield of the control soil. The yields were recorded as 12.09, 11.05 and 4.15 Mg ha<sup>-1</sup> for the 2 cm, 5 cm and control treatments, respectively. Soil moisture was maintained at more than field capacity under the porous $\alpha$  treatment (i.e. 0.08 to 0.09 cm<sup>3</sup> cm<sup>-3</sup>), whereas under the control it was < 0.04 cm<sup>3</sup> cm<sup>-3</sup>. Extracted soil solution analysis detected greater levels of ammonium and potassium in porous $\alpha$  layered soil as compared to those of the control. However, nitrate content was observed to be higher under the control (1.56 mg L<sup>-1</sup>) than under the porous $\alpha$  at 2 cm (0.96 mg L<sup>-1</sup>) and 5 cm layer (0.80 mg L<sup>-1</sup>) treatments. Comparing both porous $\alpha$  layers, the 2 cm thickness proved to be more efficient in terms of crop productivity. This experiment demonstrated that porous $\alpha$  material can be used in the cultivation of sandy soils practically in dryland. Not only does it save water but it also improves nutrient management and improves crop production.

**Key words:** Dryland, porous $\alpha$  amendment, sustainability, water saving.

### Introduction

Limited availability of water for irrigation can restrict growth and production in many irrigated crop areas, particularly in semi or arid regions. Water supplies that rely solely on precipitation are often limited and erratic. Water shortages have heightened the importance of water in agricultural production<sup>1,2,4,6,7</sup>. Rarely there is sufficient precipitation during a growing season that allows a crop to produce at its potential limit<sup>15</sup>. Such limitations on water make it crucial to find ways to best utilize this limited resource through optimal irrigation combined with innovative modifications of soil<sup>13</sup>. This necessitates the need for water conservation that can be achieved through supplementary irrigation in the root zone.

Soil amendments are substances that improve the physical properties of soil to promote plant growth<sup>3,14</sup>. Application of soil amendments and good water management can be necessary to obtain reasonable yields<sup>8</sup>. Many authors have suggested that inorganic amendments should be used in sandy soils in order to increase plant available water and to improve CEC<sup>3,5</sup>.

Data from vegetable producing semi-arid regions of Mauritania indicates that production has decreased during the last decade. Irrigation in this region is usually gravity fed hence water application efficiency is very low. The need for new irrigation systems and improvements in existing practices, at least in intensive vegetable producing regions, has been identified. Drip irrigation is the most efficient system in delivering the optimal amount of water directly into the crop root zone<sup>9-12</sup>. The use of such a system is particularly important where water resources are limited. However, the costs of installation and maintenance, as well as the technical skills required for its operation are high.

Nevertheless, for future planning purposes it is necessary to obtain background information about appropriate management practices for drip systems with soil amendments. Thus, a greenhouse experiment was conducted in order to assess the effects of two different thickness layers of porous $\alpha$  on the yield of Swiss chard watered with a drip irrigation system (DIS).

A second experiment was conducted in the laboratory and used a cylinder to check the amount of water infiltration and the side effects of porous $\alpha$ . Furthermore, the purpose of this leaching experiment was to compare the ability of porous $\alpha$  to hold water and its effects on electrical conductivity (EC) and pH of the soil, as this material showed high EC and high pH.

No previous information had been collected about the effects of porous $\alpha$  on the physical properties of soil and on sandy soil growing vegetables. The objective of this study, therefore, was to investigate the effect of a porous $\alpha$  amendment on soil properties and plant growth in sandy soil under a drip irrigation system.

### Materials and Methods

**Greenhouse experiment:** The experiment was conducted in a greenhouse in the Arid Land Research Center, Tottori, Japan. The textural composition of the soil used was 95% sand, 1.3% silt and 3.7% clay and is usually referred to as dune sand. The water holding capacity of this soil sand is 0.05 cm<sup>3</sup> cm<sup>-3</sup> (0.027 cm<sup>3</sup> cm<sup>-3</sup> is the wilting point and 0.08 cm<sup>3</sup> cm<sup>-3</sup> is the field capacity, and these correspond to matric potentials of -0.0055 and -1.6MPa, respectively). The characteristics of the sand dune soil used during the experiment and those of porous $\alpha$  are given in Table 1.

**Table 1.** Selected physicochemical characteristics of the sand soil and porous $\alpha$  material.

Property	Value	
	Sand	Porous $\alpha$
EC dS m <sup>-1</sup>	0.012	8.36
pH	6.68	10.3
Exchangeable K <sup>+</sup> cmol kg <sup>-1</sup>	3.3	3.24
Exchangeable Ca <sup>2+</sup> cmol kg <sup>-1</sup>	3.4	31.76
Exchangeable Mg <sup>2+</sup> cmol kg <sup>-1</sup>	0.17	0.37
Exchangeable Na <sup>+</sup> cmol kg <sup>-1</sup>	0.14	0.15
Cation exchange capacity cmol kg <sup>-1</sup>	0.40	2.51
Bulk density g cm <sup>-3</sup>	1.57	1.1 ~ 1.3
Hydraulic conductivity cm s <sup>-1</sup>	0.052	0.0022

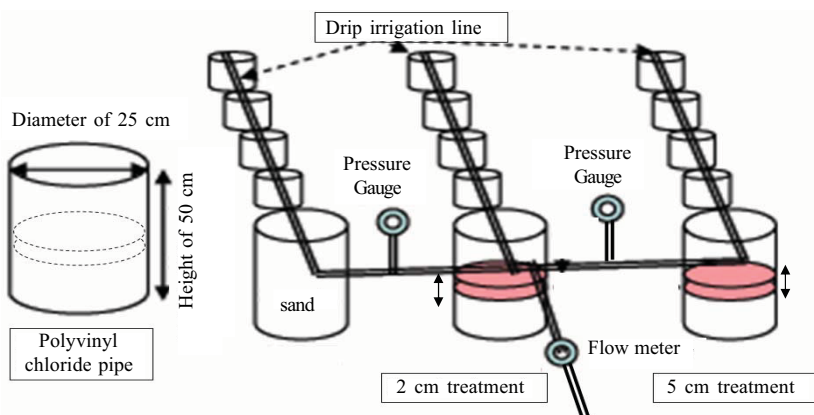
The experiment was set in a pot (0.25 m diameter, 0.5 m long) that was inserted into the soil. Treatments were randomly replicated five times, resulting in application to 15 pots. Treatments consisted of two porous $\alpha$  layers of 2 and 5 cm thickness placed in the soil at a depth of 30 cm and one control treatment. Daily irrigation was equivalent to 50% of open-pan evaporation, which was measured in the greenhouse.

Swiss chard was sown in lateral lines along the emitters on 20<sup>th</sup> April, 2008, with 16 plants sown per pot. After 2 weeks, three plants remained in each pot. All plants were harvested on 15<sup>th</sup> July, 2008. A liquid NPK fertilizer (8:8:8) was applied to the pots every 10 days.

The experimental area was irrigated using a drip irrigation system (DIS). Emitters were placed 40 cm apart. The discharge rate of each emitter was 2 L h<sup>-1</sup>, which was maintained by an operating pressure of 0.1 MPa (Fig. 1).

Water irrigation commenced two weeks after the plants were sown and continued until harvesting. However, for the first two weeks, the control received 75 mm of water, while only 44 mm was used for the porous $\alpha$  treatments. The total water input in the control was around 388 mm, while that for the porous $\alpha$  treatments was around 359 mm.

**Leaching experiment:** The experiment was carried out using a cylinder (50 cm long x 10 cm diameter) in the Sub Division of Soil Conservation, Arid Land Research Center, Tottori University, Japan. The treatments consisted of two porous $\alpha$  layers of 2 and 5 cm thickness placed at a depth of 15 cm in the soil and one control treatment with three replications. The experiment was run for one week and repeated twice. Eight mm of water was applied daily. A leaching sample was collected continuously and tested for



**Figure 1.** Schematic view of the greenhouse experiment using porous $\alpha$  layered in sandy soil.

electrical conductivity and pH. At the end of the experiment, we measured the water content, EC and pH using soil sampling in the top 15 cm, bottom 10 cm and porous $\alpha$  material. After we dried the porous $\alpha$  material using an oven (105°C for 48 h), we reinserted it into the cylinder along with new sand soil and repeated the experiment.

**Porous $\alpha$  amendment:** Porous $\alpha$  is the commercial name of the material that was tested, which is recycled from used glass bottles obtained from household rubbish. According to the Tottori Institute's research on recycling, this material is produced by taking glass bottles that were discarded by households and by firing them at approximately 1000°C. Chemical properties of this material are given in Table 2.

**Soil and water measurement:** Water samples from each treatment were collected during harvesting with the use of a suction method. Each sample was collected from a depth of 15 cm. At the end of the experiment, soil samples were taken from a depth of 40 cm. Due to low water availability at 40 cm depth, particularly in porous $\alpha$  treatments, we could not obtain any water samples using suction. Nitrate (NO<sub>3</sub>), nitrogen (NO<sub>2</sub>), ammonium (NH<sub>4</sub>) and potassium (K) concentrations in the water samples were analyzed using an ion chromatograph (UV-1200, Shimadzu Co. Ltd., Japan). P concentration was measured by spectrophotometry.

**Statistical analysis:** The mean, standard error and significance were obtained using Duncan's multiple-range test ( $P \leq 0.05$ ), which was performed on the data using the SPSS and SAS/Stat (1991) software packages.

## Results and Discussion

The amount of water applied to the treatment as compared to the control indicated that the addition of porous $\alpha$  to soil can increase water storage capacity necessary for plant growth. Water applied in the control immediately filtered below the root zone.

Table 1 shows the physicochemical characteristics of sand and the porous $\alpha$  amendment. Results showed that the concentration of exchangeable Ca<sup>2+</sup> was much higher as compared to that found in regular sand soil. CEC was six times greater in porous $\alpha$ -treated soil than in regular sandy soils, indicating that this amendment could enhance soil fertility by allowing it to hold more nutrients.

Fresh yield was higher under the porous $\alpha$  2 cm followed by porous $\alpha$  5 cm treatments, recorded at 12.09 and 11.05 Mg ha<sup>-1</sup>, respectively. The difference between the two porous $\alpha$  treatments was not significant. This result can be explained by the fact that more water was retained in the top 15 cm of the soil under the 5 cm thickness condition, which in turn, could have affected aeration and hence directly affected crop growth. Fresh crop yield under the control was significantly lower (60%) as compared to that found for the porous $\alpha$  condition, 4.15 Mg ha<sup>-1</sup>.

Water use efficiency represents a given level of fresh yield per unit of water consumed physiologically by a crop. Highest

**Table 2.** Chemical properties of the porous $\alpha$  material.

Element	Percentage
Calcium (Ca)	49.1
Silicon (Si)	39.2
Sodium (Na)	5.6
Iron (Fe)	3.3
Sulfur (S)	1.5
Potassium (K)	1.1

water use efficiency was observed under the porous $\alpha$  treatments, while efficiency was very low under the control treatment (Table 3). The management of soil water content is very important to crops grown in sandy soil, which is characterized by a low water holding capacity. We believe that crop growth was poor under the control due to low water content as compared to the porous $\alpha$  amendment.

Soil analysis data showed significant differences between the control and the porous $\alpha$  amendments in the top 10 cm (Table 4).  $\text{NO}_3^-$  was higher under the control condition,  $1.56 \text{ mg L}^{-1}$ , indicating possibility of leaching down compared to  $0.96$  and  $0.80 \text{ mg L}^{-1}$  for 2 cm and 5 cm porous $\alpha$  treatments, respectively. The same was observed for phosphorus (P),  $\text{NH}_4^+$  and K, which were higher under the control, while  $\text{NO}_2^-$ , Mg and Ca were higher under the porous $\alpha$  treatments (Table 4).

The soil sample from a 40 cm depth showed no significant differences among the treatment and control conditions (data not shown). We believe that under the porous $\alpha$  amendment, very little water filtered down to that depth, as the water content was observed to be  $0.07$  to  $0.09 \text{ cm}^3 \text{ cm}^{-3}$  at the 10 cm depth while it was  $0.03$  to  $0.035 \text{ cm}^3 \text{ cm}^{-3}$  at 40 cm. However, the control treatment did not show any significant differences at this depth. The hypothesized reason for this result is that the amount of water supplied by the drip method was very low, and not enough to have caused nutrient leaching.

Electrical conductivity of soil extract was not significantly different among treatments. The highest EC was observed under the 5 cm porous $\alpha$  treatment followed by 2 cm and the control,  $0.62$ ,  $0.43$  and  $0.18 \text{ dS m}^{-1}$ , respectively, at a depth of 10 cm. For a 40 cm depth there were no significant differences in soil electrical conductivity of soil extract. The highest EC was observed under the 5 cm porous $\alpha$  treatment followed by 2 cm and the control,  $0.62$ ,  $0.43$  and  $0.18 \text{ dS m}^{-1}$ , respectively, at a depth of 10 cm. For a 40 cm depth soil samples, the  $\text{EC}_{1:5}$  was very low,  $0.026$  and  $0.039 \text{ dS m}^{-1}$  for the control, 2 cm and 5 cm porous $\alpha$  treatments, respectively. Soil pH was not significantly different in treatments at 10 cm or 40 cm depth.

**Table 3.** Total irrigation, fresh yield, water use efficiency and their probabilities.

	Total irrigation water input (mm)	Yield fresh weight ( $\text{Mg ha}^{-1}$ )	P- value	Water use efficiency ( $\text{g fresh weight L}^{-1}$ )
Control	440	4.15a	0.005	1.07a
Porous $\alpha$ (2 cm)	369	12.09b	0.001	4.91b
Porous $\alpha$ (5 cm)	369	11.05b	0.003	4.49b

Different letters in the column indicate different significance levels obtained using Duncan's multiple range tests at  $P \leq 0.005$ .

**Table 4.** Total nutrient concentration of extract water at 10 cm depth ( $\text{mg L}^{-1}$ ).

	$\text{NO}_2^-$	$\text{NO}_3^-$	$\text{NH}_4^+$	P	K	Mg	Ca
Control	0.42a	1.55b	0.62a	4.0b	0.88a	0.02a	0.11a
Porous $\alpha$ (2cm)	1.32b	0.96a	1.17a	0.9a	1.37b	2.44b	3.65ab
Porous $\alpha$ (5cm)	3.43c	0.80a	1.42a	1.0a	2.60b	7.05b	16.29b

**Leaching experiment:** Fig. 2 presents the accumulation of leached water during 8 days. The porous $\alpha$  case showed less water leaching. During the first experiment, the amount of water was 37 and 22 mm for the 2 and 5 cm thickness, respectively. This amount was decreased in the second experiment to 20 and 12 mm, respectively. However, in the control, water leaching was similar in each experiment, around 56 and 53 mm. Thus, our results implying that porous $\alpha$ -treated soil can hold more water than regular sand may help crop growth in dry conditions. Statistical results showed that after using this material for two seasons, infiltration will probably decrease. Therefore, treatment with a 5 cm thickness is not recommended, as it will affect aeration and decrease crop production.

Electrical conductivity and pH variation during the leaching experiment are presented in Fig. 3. The porous $\alpha$  treatment showed high salinity as compared to the control. The highest salinity was observed under the 5 cm thickness ( $1.08 \text{ dS m}^{-1}$ ) condition during the second day of leaching, after which it decreased. The second porous $\alpha$  2 cm treatment showed the highest EC,  $0.42 \text{ dS m}^{-1}$ . Yet after three days, its level was nearly the same as in control. The second experiment showed that the 2 cm thickness of porous $\alpha$  was equal to that of the control, hence implying no effect of porous $\alpha$ , while the 5 cm condition showed an increase of EC during the first three days, with the highest recorded value being  $0.51 \text{ dS m}^{-1}$ . Statistically, pH variation was not significant among all of the treatments. However, the 5 cm thickness showed the highest pH value of 7.5.

Soil sampling data of  $\text{EC}_{1:5}$  and  $\text{pH}_{1:5}$  are presented in Fig. 4. As shown in this figure, the top 15 cm of the soil was not affected by porous $\alpha$  and showed no significant differences between EC and pH regardless of the treatment. The bottom 10 cm of the treated soil was recorded to have a decrease of EC during the second experiment. However, a higher pH level was found in the porous $\alpha$  treatments. In both experiments the value exceeded 8. The trend of  $\text{pH}_{1:5}$  was decreased in the second experiment, with results similar to those of leaching water. This data suggests that the effect of this material will probably be negligible after one or two years of its use under a condition of 2 cm thick layers.

Table 5 presents water content in the top 15 cm, bottom 10 cm and in the porous $\alpha$  material. Water content was higher under the 5 cm thickness condition in both experiments. Data from the bottom 10 cm layer also suggests that the water content in the 5 cm thickness was higher. However, the water content of this condition was reduced in the second experiment, which was probably due to low permeability in the porous $\alpha$  material.

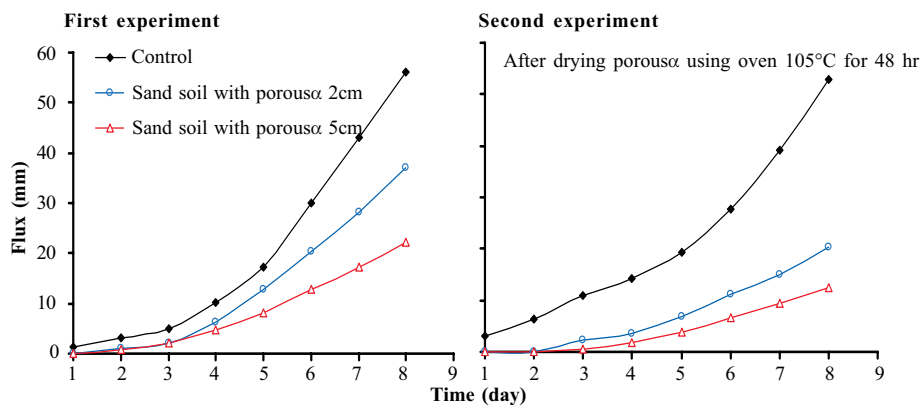


Figure 2. Accumulation of flux under two different layers of porous $\alpha$  (2 cm and 5 cm thickness) and the control during a leaching experiment.

Table 5. Water content in the top and bottom of the cylinder and porous $\alpha$  material at the end of leaching experiments.

	Water content at the top 15 cm		Water content at the bottom 10 cm		Water content in porous $\alpha$	
	First experiment	Second experiment after drying porous $\alpha$	First experiment	Second experiment after drying porous $\alpha$	First experiment	Second experiment after drying porous $\alpha$
Control	0.08±0.01a	0.08±0.01a	0.08±0.04a	0.08±0.03	--	--
Porous $\alpha$ (2cm)	0.17±0.07b	0.19±0.06b	0.20±0.01b	0.15±0.04	0.22±0.01a	0.24±0.02a
Porous $\alpha$ (5cm)	0.24±0.13b	0.25±0.08b	0.22±0.1	0.13±0.02	0.21±0.01a	0.22±0.03a

± Standard error.

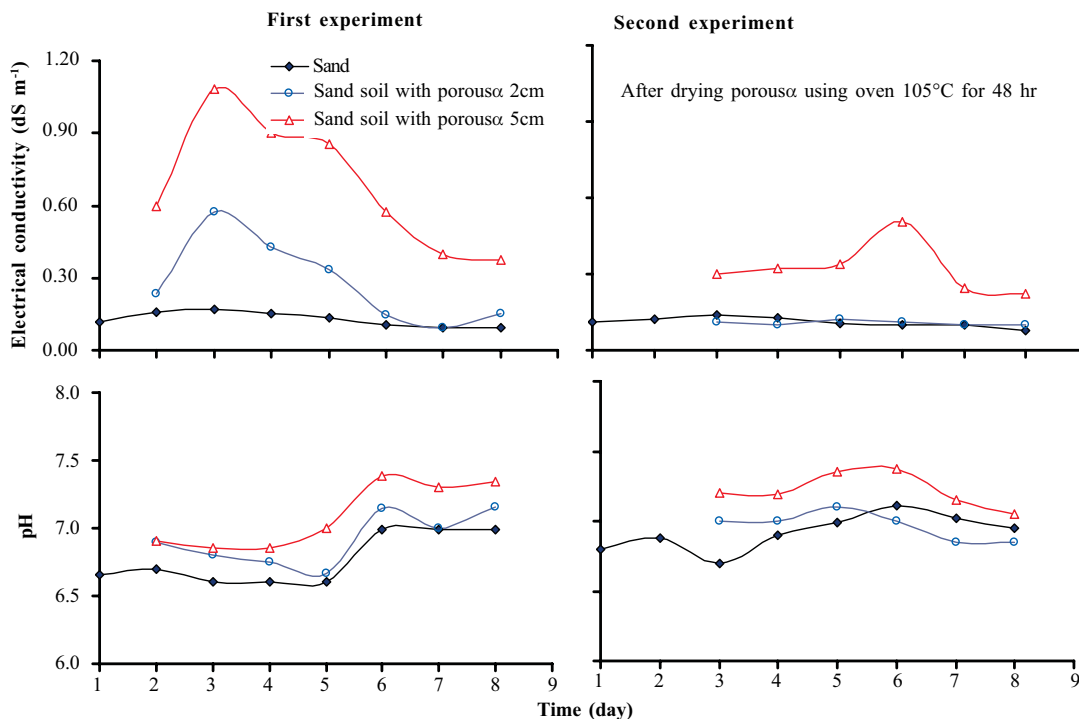
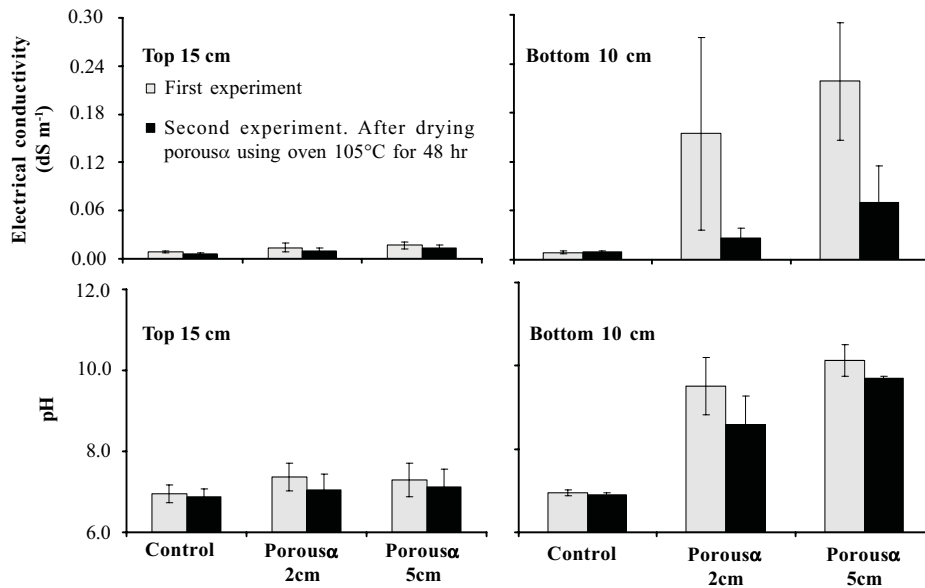


Figure 3. Electrical conductivity and pH of leaching water.

The use of the porous $\alpha$  material yielded a higher water concentration under the 2 cm as opposed to the 5 cm thickness condition. This may be attributed to drainage retention properties. However, the difference between these two porous $\alpha$  treatments was not significant, while it was significantly different from the control.

### Conclusions

This study evaluated the effect of different porous $\alpha$  layers on water availability in sandy soil. A measure of fresh yield and water use efficiency of Swiss chard grown in a sand dune with the amendment of porous $\alpha$  indicated that this treatment could improve crop production and water availability. At the same time, the control



**Figure 4.** Electrical conductivity ( $EC_{1:5}$ ) and pH ( $pH_{1:5}$ ) measures obtained from soil sampling at the end of a leaching experiment.

condition showed a very low fresh yield as compared to both of the porous $\alpha$  treatments. This difference is attributed to the low water holding capacity and rapid percolation losses in this type of dune sand. An extracted soil solution analysis indicated that this amendment increased nutrient availability in sandy soil.

A leaching experiment demonstrated that the EC and pH negative effect of this amendment is almost negligible, at least under the 2 cm thickness condition. Therefore, we recommend the use of a 2 cm thick layer of this amendment in sandy soil. However, we do not recommend the use of a 5 cm thick layer, as it might adversely affect the soil and crop growth. In general, we conclude that a layer of the porous $\alpha$  that was tested in this study can be used to irrigate vegetables grown in sandy soils of semi-arid regions at input levels equivalent to 50% of pan evaporation. We recommend the use of a drip irrigation system for such an irrigation option in sandy soils. More studies on the effects of porous $\alpha$  will be conducted in future both in the field and in a laboratory setting.

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#### References

<sup>1</sup>Bessembinder, J.J.E., Leffelaar, P.A., Dhindwal, A.S. and Ponsioen, T.C. 2005. Which crop and which drop, and the scope for improvement of water productivity. *Agric. Water Manage.* **73**(2):113–130.

<sup>2</sup>Inoue, M., Ould Ahmed, B.A., Saito, T., Irshad, M. and Uzoma, K.C. 2008. Evaluation of three dielectric moisture sensors under saline sandy soil condition. *Soil Use and Manage.* **24**(2):156-162.

<sup>3</sup>Li, D., Joo, Y.K., Christians, N.E. and Minner, D.D. 2000. Inorganic soil amendment effect on sand-based sports turf media. *Crop Sci.* **40**: 1121-1125.

<sup>4</sup>Lingle, G.R. and Franti, T.G. 1998. What is The Cooperative Agreement for Endangered Species Habitat along the Central Platte River? NebFact NF98-375. University of Nebraska-Lincoln Cooperative Extension Publication, 5 pp. Available at <http://ianrpubs.unl.edu/wildlife/nf375.htm>.

<sup>5</sup>McCoy, E.L. and Stehouwer, R.C. 1998. Water and nutrient retention properties of internally porous inorganic amendments in high sand content root zones. *J. Turfgrass Manag.* **2**:49-69.

<sup>6</sup>McGuire, V.L. 2004. Water-level changes in the high plains aquifer, predevelopment to 2002, 1980 to 2002, and 2001 to 2002. Fact sheet 2004-3026. U.S. Geological Survey, Lincoln.

<sup>7</sup>McGuire, V.L. and Fischer, B.C. 1999. Water-level changes, 1980 to 1997, and saturated thickness 1996-1997, in the high plains aquifer. Fact sheet 124-99. U.S. Geological Survey, Lincoln.

<sup>8</sup>Mustafa, M. A. And Abdel Magid, E. A. 1981. The effect of irrigation interval, urea-N and gypsum on salt distribution in highly saline-sodic montmorillonitic clay soil under forage sorghum. *Soil Sci.* **132**:308-315.

<sup>9</sup>Ould Ahmed, B.A., Yamamoto, T., Fujiyama, H. and Miyamoto, K. 2007a. Assessment of emitter discharge induced by polluted water of microirrigation system. *Irrig. and Drainage System* **21**(2):97-107.

<sup>10</sup>Ould Ahmed, B.A., Yamamoto, T. and Inoue, M. 2007c. Impact of leaching on sustainability of sorghum production on dune sand under drip irrigation with saline water. *Transaction of the ASAEB. J.* **50**(4):1279-1286.

<sup>11</sup>Ould Ahmed, B.A., Yamamoto, T., Rasiyah, V., Inoue, M. and Anyoji, H. 2007b. The impact of saline water irrigation management options in a dune sand on available soil water and its salinity. *Agri. Water Manage.* **88**(2-3):63-72.

<sup>12</sup>Shalhevet, J. 1991. Using water of marginal quality for crop production: major issues. In Shalhevet, J., Cangmimig, L. and Yuexian, X. (eds). *Water Use Efficiency in Agriculture*. Proceedings of the Binational China-Israel Workshop, Beijing, China, Peril publ. Rehovot, Israel, pp. 17-53.

<sup>13</sup>Singh, R., van Dam, J.C. and Feddes, R.A. 2006. Water productivity analysis of irrigated crops in Sirsa district, India. *Agric. Water Manage.* **82**:253–278.

<sup>14</sup>Wallace, A. and Terry, R.E. 1998. *Handbook of Soil Conditioners: Substances that Enhance the Physical Properties of Soil*. Marcel Dekker, New York.

<sup>15</sup>Willis, W. O. 1983. Water conservation: Introduction. In Dregne, H.E. and Willis, W.O. (eds). *Dryland Agriculture*. Agron. Monogr. 23. ASA, CSSA, and SSSA, Madison, WI, p. 25.