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Effectiveness of compost use in salt-affected soil in an automated greenhouse irrigation system

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Abstract. Salinity problems reduce productivity on both irrigated and non-irrigated agricultural lands. Saline soils occur in arid and semi-arid regions where rainfall is insufficient to meet the crops' water requirements and leach mineral salts out of the root-zone. Compost can play an important role in managing, mitigating, and improving the soil salinity negative effects. In this work, the compost effects on salt affected soil were studied. Therefore, physico-chemical parameters and morphological status of the plants divided into four plots in a greenhouse were studied. The first plot P0 is a control plot which was irrigated by fresh water, P1 was irrigated with fresh water mixed with compost, P2 and P3 were irrigated by saline water with an NaCl concentration of 5 g/L. An automated irrigation system was implemented to manage plots irrigation. The system was based on an electronic board and multiple sensors to track ambient temperature and humidity in the greenhouse, soil moisture and temperature of each plot, data was stored in a SD card. The results obtained showed that compost use increased stem growth by 23%, this percentage was improved by 10% for greenhouse tests. ***Keywords***: Soil salinity; saline water; compost; connected greenhouse.

1 Introduction

Soil salinization poses a real danger to food security because it negatively affects crop yields and can cause serious damages to land. This goes back to huge population growth over the past decades, which is still on track to increase to around 9.1 billion by 2050, requiring food production of over 70%, according to the FAO as mentioned in 2009 [1].

Worldwide, more than 33% irrigated soil and 6% of the total land area are affected by salinity [2].

Salinization comes partly from natural phenomena; in fact, the soil can be naturally rich in salts due to carbonaceous minerals or feldspar, or due to capillary effects. Generally, salt accumulation at or near to the soil surface defines a primary salinity [3].

Nevertheless, human activities also have an amplifying effect due to the agricultural activity intensification, and the poor combination of high evapotranspiration and unsuitable supply of irrigation water in relation to its salt content. Moreover, soil salinization caused by irrigation reduces the area of irrigated arable land by 1-2% per year [4].

The risky areas are those with arid to semi-arid climates. The more severe aridity, the more essential irrigation need is for cultivation [5].

As examples, Morocco and Tunisia are countries with an arid to semi-arid climate, threatened by soil salinization, since more than 5% of the surface of Morocco and 8% of Tunisia are already affected by salinization [6]. Among the main causes of soil salinity: a climate dominated by low precipitation results from unfavorable evapotranspiration rates and soil characteristics that limit leaching [7]. Then, salty groundwater can reach the upper layers of the soil and thus provide salt to the root zone [8].

Furthermore, the use of fertilizers and other inputs associated with irrigation and insufficient drainage [9], as well as treated industrial wastewaters that are rich in salt for irrigation or surface storage cause soil salinization [8]. The aim of this study is to investigate the effect of salinity and the compost produced by biodegradable organic waste on the gemination seeds and the plant growth, especially, on the aerial parts. Also, showed the difference between culture under connected greenhouse and classical culture.

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2 Materials and Methods

2.1 Automated irrigation system for greenhouse

In order to ensure the ideal conditions for crops, a mini experimental greenhouse was designed; the proposed system is presented in Figure 1**.** It is designed in order to automate the irrigation process, it is monitored by sensors to collect information on the interior and exterior ambient temperatures, humidity in the greenhouse, luminosity, CO_2, and soil moisture, as well as temperature of each of the plots. The system is based on an Arduino MEGA 2560 board, a DHT22 module used to sense both interior and exterior ambient temperature and humidity; the DS18b20 sensors are used to acquire soil temperature, and capacitive soil moisture sensors are used to monitor soil moisture and a photo-resistance to get light intensity. Data is stored on an SD card to allow further data treatment and analyses. Each parcel was irrigated when the solenoid valve was opened; each of solenoid valves were controlled by a relay module. Sensors and modules specifications are presented in Table 1. The operation of the irrigation system is managed as follows: after the acquisition of temperature and humidity data by the designated sensors, then their processing by the electronic card. The latter gives the command setpoint to the solenoid valves for opening or closing. Indeed, if the soil temperature is below 10°C (the optimum temperature for growing fenugreek [10]) the system must stop irrigation, even if the humidity threshold has not yet been reached, to increase the temperature, the card gives the instruction for closing the solenoid valve through the relay which supplies the latter with power. Since fenugreek does not require a strong need for water and it tolerates drought [11], we limited ourselves to a humidity threshold of 40%. So, if the sensor sends a value greater than 40% the system stops irrigation, otherwise, if the value is less than 40% the system gives the set point for activating the solenoid valve [12,13].

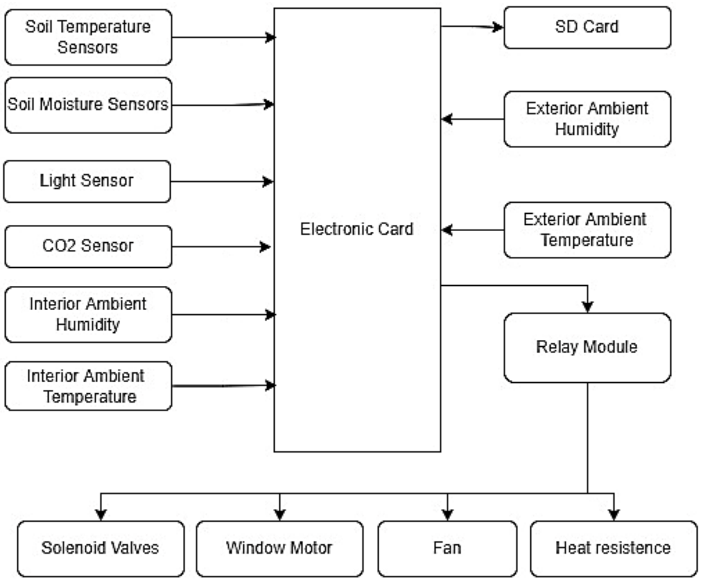

Fig. 1. Automated irrigation system based on an electronic card architecture.

Table 1. Parameters configuration of the greenhouse control.

	Parameters	Sensor / Module	Operating Voltage	Range	Accuracy
INPUTS	Ambient humidity	DHT22	3 to 5V	0-100%	2-5%
	Ambient Temperature			-40 °C to 80 °C	± 0.5 °C
	Soil Moisture	Capacitive soil Moisture sensor	3.3V to 5V DC	0-100%	±2%
	Soil Temperature	DS18B20	3V to 5V	-55 °C to +125 °C	± 0.5 °C
	CO_2	MQ135	5V	-	± 2 ppm
	Real Time Clock	DS3231	3.3 V to 5.5 V	-	-
OUTPUTS	Storage	Micro SD Module	4.5V - 5.5V DC	-	-
	Outputs Control	Relays Module	3.75V to 6V	-	-

2.2 Fenugreek seeds choice

The investigated plant was of the Fables order, in the family of the Fabaceae. It was of the genus Trigonella and species of foenum-graecum: *Trigonella foenum-graecum* L., known as fenugreek. It grows and thrives best in rich and well-drained soil or sandy-loamy soils, with a pH of 5.3 - 8.2 exposed to full sun. Its culture requires relatively little humidity. As a leguminous plant, it needs little or no nitrogen fertilizer as it can fix nitrogen and enrich the soil [14].
The germination period of fenugreek seeds in the ground usually ranges between 3 and 10 days. Germination is epigeal. Six to ten days after germination, the first single leaf appeared. The first trifoliate leaf formed after another 5 or 8 days. Flowering usually occurs 60 days after planting fenugreek. Seeds are ready to harvest 30-35 days after flowering. Fenugreek is considered as a plant with moderate salt stress tolerance [15].

2.3 Seed germination

To study the salinity effect on the fenugreek seeds germination, firstly, a germination test was carried out with saline water at 5 g/L of NaCl. This concentration was selected after preliminary tests carried out in Tunisia through collaborative work. Indeed, a germination test was conducted by applying saline water at different concentrations (23.4 g/L, 11.7 g/L, 5.85 g/L, 2.925 g/L, and 1.47 g/L) on tomato seeds. These concentrations were chosen based on the salinity of the waters of the wells in Tunisia as a maximum value, then the concentration was reduced until arriving at the salinity of the fresh water used by the citizens in Tunisia. The results obtained showed that the inhibition started from the second concentration of 5.85 g/L.
After disinfection of the fenugreek seeds with sodium hypochlorite (NaClO) [16], they were washed with distilled water. They were then put to germinate in Petri dishes lined with filter paper moistened with distilled water for the fresh water control Td 10 mL, with saline water for the salty water control Ts, a third case was studied to experiment with the compost effect on salinity, compost extracts were added at different concentrations (10%, 25%, 50% and 75%) for both distilled and salty water. The compost extracts were prepared according to standards (10 g of compost in 100 mL of distilled water) [17].
Finally, the germination index (GI) was calculated according to the following equation (1) [18]:

$$GI = \frac{N_s}{L_c} \times \frac{L_s}{N_c} \times 100 \qquad (1)$$

Where :

- GI : Germination index.
- N_c : Number of germinated seeds irrigated by water (control).
- N_s : Number of germinated seeds irrigated with the sample.
- L_c : Total radical length of germinated seeds in the control.
- L_s : Total radical length of germinated seeds in the sample.

Petri dishes were incubated in a dark medium at 25 °C for 3 days.

1.1. Cultivation of fenugreek seeds

After the germination test, the effects of salinity and compost on the growth of the fenugreek seedling were investigated, it was the cultivation of the seeds. We studied two different cases, the first was to put the crops under normal weather conditions and the second was to repeat the same experiment in a controlled environment which was a connected greenhouse.
Casablanca's climate is semi-arid with temperatures ranging from 12.7 °C in winter to 21 °C in summer, as it is located on the Moroccan Atlantic Coast [19].
The soil used in this study is loamy-sandy [19], it was recovered from the garden areas of the school, and it is a soil of low organic matter content. Its physico-chemical characteristics are presented in Table 2.
The compost used in this study is produced by our research team in a previous work [20]. It is made up of : green waste, spent olive pomace, poultry droppings and vegetable water. Its parameters are shown in Table 2.

Table 2. Physico-chemical parameters of soil and compost.

Physico-chemical parameters	Soil	Compost
pH	7.47	6.42
Electrical conductivity (µS/m)	353	4672
Humidity (%)	0.31	ND
Organic matter content (%)	1.63	ND
Total organic carbon (%)	3.59	24.32
Total Nitrogen Kjeldahl (%)	0.72	0.92
Carbon / Nitrogen (C/N ratio)	4.98	26.43
Phosphorus P^+ (mg/kg)	< 0.001	ND
Potassium K^+ (mg/kg)	33.5	ND
Sodium Na^+ (mg/kg)	164.6	ND
Calcium Ca^{++} (mg/kg)	109.4	ND

***ND :** Not determined.*

For irrigation, four different experimental protocols were followed: irrigations with fresh water, with saline water, with fresh water mixed with 5g/L compost (a concentration of 25% according to the test of germination), and irrigation with saline water mixed with compost (same concentration), irrigation was controlled using an automatic system. The chemical and physical characteristics of fresh water used to irrigate the studied culture are presented in Table 3.

Table 3. Physical and chemical fresh water analyses.

Parameters	Fresh water
Redox potentiel (mV)	180
Water temperature (°C)	25.0
Ambient temperature (°C)	30.0
pH	7.46
Electrical conductivity (µS/cm)	2670
Turbidity (NTU)	0.45
Dry residue at 105 °C (mg/L)	1760
Sodium Na^+ (mg/L)	198
Potassium K^+ (mg/L)	1.00
Limit detection of Calcium Ca^{2+} (mg/L)	104
Total iron (mg/L)	< 0.03

3 Results and discussion

3.1 Salinity effect on seed germination

Salinity induces a negative effect on the germination of fenugreek seeds and especially on their length over time. This is shown in Figure 2 which presents the germination index for the different fresh and saline waters with the different concentrations of the compost. The seeds soaked with fresh water mixed with the compost extract have undergone a total germination of 100% for all the seeds with the different concentrations of the compost extract with germination indices which exceed 70% which is the GI required for organic fertilizers according to the Chinese standard NY525-2021 [21] (IG10%=110%, IG25%=127%, IG50%=134%, IG75%=118%). On the other side, fenugreek seeds weted with compost extract and saline water, 3% of the seeds suffered a total inhibition of germination for the different doses of compost. Despite this, the germination indices were exceeded 70 % except for the 75% concentration (IG10%=82%, IG25%=92%, IG50%=92%, IG75%=58%). This can be expressed by the accumulation of the salinity of the water with that of the compost, especially when the concentration is significant and too high, which pushes the plant to present a deficit in its ability to absorb water [22].

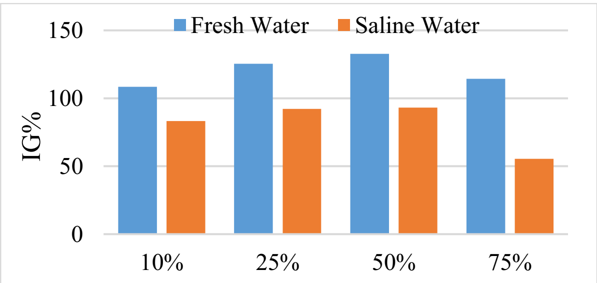

Fig. 2. Fenugreek germination index on saline and fresh water with different compost concentrations (10 to 75%).

These results revealed that there is a significant inhibition at the level of the seeds soaked with only saline water compared to those moistened with the compost extract prepared with saline water. The latter showed very significant growth compared to the controls, especially at the 25% and 50% concentrations, the germination indices were 125% and 135% respectively.

3.2 Effect of salinity on aerial parts length

After the results obtained during the germination test, the concentrations which gave the best results are 25% and 50%. Since the salinity accumulates, we chose to work with the lowest dose which is 25% for study plant growth. In a first phase, the growth parameter that was followed is the length of the stems. Salinity induced a reduction in the length of the aerial part of fenugreek plants (Figure 3).

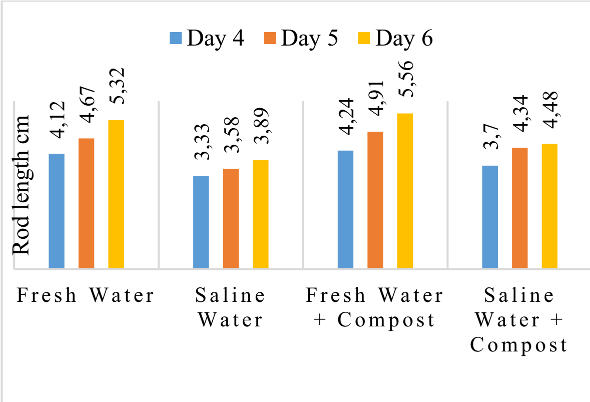

Fig. 3. Rod length of fenugreek seedlings at 4, 5, and 6 days of salt and fresh water and salt and fresh water with compost in the normal weather conditions.

The length of the aerial part in the control plants under normal Casablanca weather conditions is 5.32 cm after 6 days. This length decreased and reached 3.89 cm, which corresponds to a respective decrease of 24%. For the samples on which we applied the extract of the compost we notice a very significant increase in the length of the stems of 5.56 cm and 4.48 cm respectively with fresh water and saline water (Figure 3). For greenhouse tests, the results are very satisfactory as shown in Figure 4.

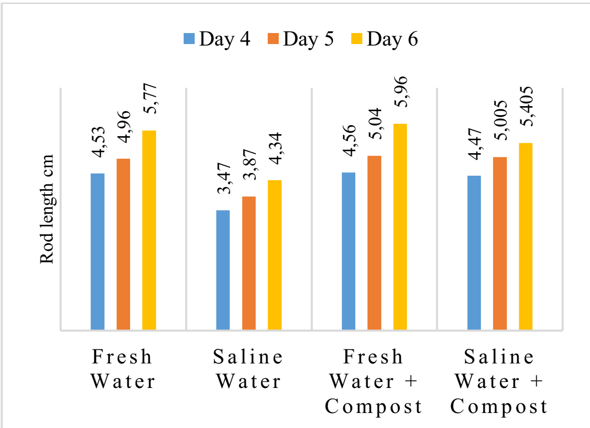

Fig. 4. Rod length of fenugreek seedlings in 4, 5, and 6 days of salt and fresh water and salt and fresh water with compost in the greenhouse.

Salt stress presents a serious and major impact on growth and development in the majority of cultivated plants [23]. The present results showed that salt stress led to the elongation decrease of the aerial part of fenugreek plants. These results are in agreement with those of Assadi (2009) [24] who observed a reduction in the growth of the aerial part of fenugreek plants under the effect of a salt concentration of 11.7 g/L. The results of the present work also showed that the use of biofertilizers and wise and well-controlled irrigation can lead to desirable results, and they can limit the harmful effects of salt stress.
Nonstop saline water irrigation redounded in egregious adverse effects on fenugreek growth, such as the reduction of stems length. High saltness can inhibit factory growth through converting ion toxicity, and osmotic stress [25]. In this study, ion toxicity was the major factor causing salt stress in fenugreek plant, because soil EC was around 0.35 mS cm −1 (Table 2) during the growing period. This is explained by the high concentration of Na^+ and Cl^- ions in the salt water compared to the control, which are considered among the main factors of ion toxicity. But the use of compost for the fertilization of the soil which is low in organic matter (1.63%) and the C/N ratio which does not exceed 4, showed a positive effect on the length of the stems. From these results it can be concluded that compost can reduce the abundance of interchangeable Na^+ in the rootzone by enhancing water infiltration and salt filtering [26,27].

4 Conclusion

Salt stress causes an important decrease in fenugreek growth and yield. This reduction was manifested by a reduction in the aerial parts elongation. Nevertheless, the use of biofertilizers based on biodegradable organic waste without chemical additives, as well as the irrigation control and the conditioning of the climate could face this problem and limit the plant risk exposition. The results of this work may be considered preliminary. Consequently, it would be interesting to study the effect of salinity on other morphological parameters such as leaves surface, and dry mass, and investigate other types of seeds. In addition, the present irrigation system could be improved with the connected greenhouse, by integrating image processing to monitor plant growth remotely as well as to detect antifungal plant-diseases.

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