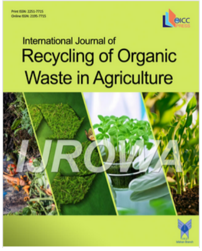

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The effect of vermicompost leachate and split root system of tomato on the growth and crop per drop

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Original Research

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Abstract:

Purpose: This study aimed to investigate the effects of vermicompost leachate on the growth and water use of tomatoes in an unequal distribution of salinity in a hydroponic system.
Method: Roots of tomato seedlings were separated into approximately two equal parts, each half was grown in a media culture part containing a 3-liter perlite and cocopeat mixture of a separated two-part box. The nutrient solution, irrigation water, and vermicompost leachate were applied for the irrigation of treatments according to the statistical design.
Results: The results showed that the treatment in which the nutrient solution was used for one side of root media culture and the leachate with the salinity of 4 dS/m on the other side had an acceptable amount of dry and fresh weight and increased crop per drop.
Conclusion: The results showed that the unequal distribution of salinity in the root media culture is an applicable technique for using vermicompost leachate although the success of this system is strongly dependent on the leachate correction.

Keywords: Hydroponic; Leachate; Tomato; Vermicompost

1. Introduction

In recent years, the world has experienced a shortage of water and a reduction in agriculture production. To fight against this problem, different methods have been suggested. Getting to optimized yield by using unusual waters is one of the human strategies for food production in agriculture. One method is to face the plant with moderate stress of salt and drought so that the plant can enhance its quality in reaction to physiological changes, and also it can reduce water consumption in terms of production in weight unit (Cuartero and Fernandez-Munoz, 1999); (Wang et al., 2003); (Sairam and Tyagi, 2004); (Plaut et al., 2004); (Errabii et al., 2007); (Passam et al., 2007); (Chookhampaeng et al., 2007); (Chen et al., 2017); (Ghoname et al., 2019), and (Filho and Bonilla, 2022). The results of some studies have shown that putting the root of tomato in unequal distribution media in terms of drought and salt improves some features of the tomato plant (Mulholland et al., 2002); (Tabatabaie et al., 2004); (Sonneveld and Voogt, 2009); (Attia et al., 2009); (Koushafar et al., 2011); (Chen et al., 2016), and (Wang et al., 2021). Using leachate as a kind of unusual water for agriculture is an effective method to fight against water crisis and salt stress, which has been considered in previous studies (Rippy et al., 2004); (Qi-Zhan et al., 2006), and (Benazzouk et al., 2018). It seems that combining these two methods leads to better results in production and reduction of water consumption, and this issue is paid attention to in this study.

The leachate of vermicompost is rich in nutrients and can be recycled as an organic nutrient solution in hydroponics; however, there is little specific procedure for such kinds of solutions in hydroponic planting (Rippy et al., 2004). For using these solutions, in addition to investigating nutrient aspects, their pollution must be considered. The aim of this study was to investigate the features of vermicompost leachate as a nutrient solution in a hydroponic unequal distribution of salts in the root media of tomato.

2. Materials and methods

Preparation of tomato seedlings

Seeds of tomato (*Lycopersicon esculentum* var. Falcato F1) were surface sterilized with 2% (w/v) sodium hypochlorite for 10 min and then germinated on the mixture of perlite and cocopeat. The vigorous 5-leaf seedlings were selected and transferred to an aerated half-strength nutrient solution: KNO_3, 3; $Ca(NO_3)_2$, 2; $NH_4H_2PO_4$, 1; $MgSO_4$, 0.50; KCl, 0.25, $ZnSO_4$, 0.001; $CuSO_4$, 0.00025; H_2MoO_3, 0.00005; and Fe-EDTA 0.025 for 12 days (Naika et al., 2005); (Koushafar et al., 2011).The seedlings were removed from the half-strength nutrient and then the roots of tomato seedlings (one seedling per box) were separated into approximately two equal parts (Koushafar et al., 2011), each half was grown in an isolated polyethylene part containing 3-liter perlite and cocopeat mixture of a separated two-part box.

Description of the greenhouse experiment

Tomato seedlings were grown in a greenhouse with a temperature of 15-22 °C, and 60-80% relative humidity in a split-root hydroponic system. The greenhouse was circular with a 2-layer plastic cover with an air insulation layer and automatic temperature regulating systems.

Nutritive solution and Vermicompost leachate

The nutrient solution, irrigation water, and vermicompost leachate were applied for the irrigation of treatments according to the statistical design. The full-strength nutrient solution contained the following salts in millimoles per liter: KNO_3, 6; $Ca(NO_3)_2$, 4; $NH_4H_2PO_4$, 2; $MgSO_4$, 1; KCl, 0.50, $ZnSO_4$, 0.002; $CuSO_4$, 0.0005; H_2MoO_3, 0.0001; and Fe-EDTA 0.050. Vermicompost leachate was provided by a manufactory in Najafabad, Isfahan. The electrical conductivity of the vermicompost leachate was set at 2 and 4 dS/m using distilled water, where the pH was adjusted to 6. Irrigation was done daily using graded dishes, in every experiment 500 milliliters of the solution was added to each side of the root media. This amount was increased to 700 milliliters in the last two weeks.

Treatments

The experiment tested seven treatments. They were distinguished according to the nature of the nutrient solution: two parts of the root media supplied with Johnson nutrient solution (JJ), plants supplied with Johnson nutrient solution in one box and 4 dS/m leachate in the other box (JP4), plants supplied with irrigation water in one box and 4 dS/m leachate in the other box (WP4), two parts of the root media supplied with 4 dS/m leachate (P4P4), two parts of the root media supplied with 2 dS/m leachate (P2P2), plants supplied with 2 dS/m leachate in one box and 4

Table 1. Concentration of various elements in the vermicompost leachate and nutrient solution.

Elements	mg/L	
	Johnson Nutrient Solution	Vermicompost Leachate
N	224	460
K	235	539
P	62	8.5
Ca	160	32
Mg	24	4.8
Zn	0.131	0.21
Cu	0.032	Not identified
Mn	0.11	0.05
Fe	2.8	1.29
Mo	0.05	Not identified
B	0.27	0.06
Cl	1.77	533
S	32	22.5
Pb	-	0.27
Cd	-	Not identified
Ni	-	0.22
Cr	-	Not identified
Na	-	5041

dS/m leachate in the other box (P2P4), two parts of the root media supplied with 4 dS/m leachate in vegetative stage and 2 dS/m in flowering stage (PPt). The nutrient solutions in each treatment were interchanged every 6 days between two parts of the root media.

Analyses

The drained volume of the solution was measured daily, and after reducing it from the total given solution to the plant, the daily water or solution use from each plant was calculated. Crop per drop was calculated through the ratio of the fresh weight of fruit yield to water consumption (Bakhshi et al., 2014). At and after harvest, plant height, stem diameter, number of expanded leaves, fresh and dry weight of root and shoots, and fruit yield were measured. The fruits were collected at the first harvest. The concentration of Ca and Mg was determined in the leachate by atomic absorbtion (AA200). Concentrations of Mn, Fe, Zn, Cu, Mo, B, Pb, Ni, Cr, and Cd were determined by atomic absorbtion (Perkin Elmer 3030). Concentration of P was measured by the spectro-photo meter (UV-visible 6505). The concentration of K and Na was measured by a flame photometer (Corning 410). To measure the concentration of total N, kjeldahl method was used.

Statistical analysis

The experiment was set up in a completely randomized design with seven treatments and three replicates. Analysis of variance was carried out using the SAS program. All data were subjected to analysis of variance and means were compared using Fisher's protected Least Significant Difference (LSD) method when the F test indicated a significance difference at $P < 0.01$. The zero value was the effect of treatment.

3. Results and discussion

The nutrient aspect of vermicompost leachate

Using leachate in agriculture to reduce water crisis, although it has some advantages, it has many limitations. High salinity, imbalance in nutrient elements, and chemical and microbial pollutants are some of these limitations (Wastewater Management. Municipal Support Division and Division., 2004). To use this leachate, the limitations should be clear and the leachate should be controlled. In the present study, the results of the analysis of the vermicompost leachate which was conducted in electrical conductivity of 4 dS/m (Table 1) showed that the concentration of phosphor, calcium, magnesium, sulfur, copper, manganese, iron, molybdenum, and boron in vermicompost leachate was less than in the Johnson nutrition solution, and the concentrations of nitrogen, potassium, zinc, chlorine, and sodium were higher. An imbalance compost leachate was used in the previous studies in hydroponic system (Jarecki et al., 2005),(Oliva-Llaven et al., 2010),(Arthur et al., 2012).

The possibility of heavy metal pollution was another limitation in this study. The results showed that the concentration of Pb, Cr, Ni, and Cd (Table 1) was less than standard (Wastewater Management. Municipal Support Division and Division., 2004). The standard amount for these metals for short-term usage are 10, 1, 2, and 0.01 mg/L consecutively, and for long-term use are 5, 0.1, 0.2, and 0.05 (Wastewater Management. Municipal Support Division and Division., 2004). Since in the present study the leachate was used short-term, therefore, the possibility of pollution was low. In addition, according to our results, the high concentration of Cl and Na in the leachate of vermicompost (Table 1) was the other main limitation in this study due to excessive Cl and Na accumulation and their toxic effects in the plants (Parra-Terraza et al., 2022).

The above results showed that for using this leachate, there were limitations of imbalance in elements and high

Table 2. Results of the evaluation of vegetation parameters in in Bolbol sites*.

Treatment	Shoot dry weight (g)	Shoot fresh weight (g)	Plant height (cm)	Stem diameter (mm)	Number of leaves Root dry weight (g)	Root fresh weight (g)	
JJ	115.9^{a}	772.7^{a}	127.33^{a}	13.45^{a}	20.33^{a}	11.4^{a}	160.8^{a}
JP4	102.7^{b}	649.24^{b}	147.33^{a}	11.53^{ab}	18.33^{ab}	9.9^{a}	115.8^{a}
WP4	15.1^{c}	103.19^{c}	84.33^{b}	9.43^{bc}	14^{d}	3.1^{b}	36.6^{b}
P4P2	18^{c}	126.33^{c}	96.33^{b}	7.93^{c}	16.33^{bc}	3.2^{b}	34.2^{b}
P2P2	14.7^{c}	105.91^{c}	87.67^{b}	8.87^{bc}	15^{dc}	2.8^{b}	37.2^{b}
P4P4	14.6^{c}	103.50^{c}	90.67^{b}	8.62^{bc}	14.67^{dc}	2.9^{b}	34.8^{b}
PPt	18.2^{c}	132.06^{c}	96.33^{b}	9.72^{bc}	16.67^{bc}	3.06^{b}	37.8^{b}

*: In each column, means with the same letter are not significantly different.

concentrations of chlorine and sodium ions. To solve these limitations, it is suggested that this leachate should be improved for future use (Jarecki et al., 2005),(Oliva-Llaven et al., 2010),(Arthur et al., 2012). Adding microelements and phosphor, calcium, potassium, and sulfur in the same amount as the difference in their concentration with Johnson nutrient solution is a way to enrich the features of leachate for future use. In this study, the electrical conductivity and acidity were set. In order to reduce the adverse effect of the vermicompost leachate, the unequal distribution of salt in the root media was used (Koushafar et al., 2011), which was one of the main purposes of this study.

Fresh and dry weight of root

The results showed that the treatment in which the nutrient solution was used in two parts of root media culture (JJ) had the highest dry weight (11.4 g) and fresh root (160.8 g) (Table 2). This result was predictable because the two sides of the root were in normal condition without any limitation. The treatment JP4 had a reduction of 13.2% and 28% in dry and fresh weight of root compared with JJ, without any significant difference, where the unequal salinity in a split–root media was an effective approach for the reduction of the adverse effects of vermicompost leachate. The limitation of high salinity, sodium toxicity, and imbalance in nutrient elements was the main reason for the reduction in root growth in other treatments (WP4, P4P4, P2P2, P2P4, and PPt), where the unequal distribution of salinity in a split-root media in these treatments cannot be an effective approach. The 6-day interval of split-root exchanging seems to be enough time for root adaptation to the salt stress while the other part could receive essential nutrients.

Dry and fresh weight of shoot, plant height, the number of leaves, and the diameter of stem

The results showed that the highest shoot dry weight (115.89 g), shoot fresh weight (772.70 g), stem diameter (13.45 mm), and number of leaves (20.33) were in the treatment JJ (Table 2) where the treatment JP4 had the highest vegetative growth after JJ (Table 2). The vegetative studied parameters in the treatment JP4 were significantly higher than other treatments (WP4, P4P4, P2P2, P2P4, and PPt). Placing one side of the root in a nutrition solution in 6-day periods was the main reason for increasing vegetative parameters in treatment JP4 compared with other treatments (WP4, P4P4, P2P2, P2P4, and PPt) in which nutrition solution was not used. At the same time, in this treatment (JP4), the other side of the root which was exposed to vermicompost leachate with the salinity of 4 dS/m faced growth limitation, so most probably some mechanisms of fighting against stress, such as an increase in abscisic acid (ABA), have been activated (Kidra et al., 2004). Returning this part of the root to a nutrition solution and a normal situation after 6 days reduces the injuries to the root. Unequal distribution of salt in root media and normal situation of one side of the root at every time has provided a suitable situation for plant growth, showing that using leachate with a nutrition solution in unequal distribution of salt in the root zone system can be an effective method.

Dry and fresh weight of fruit

The results showed that the treatment JJ had the highest dry weight (51.43 g), fresh weight (538.66 g), and number of fruits (19.4) (Table 3). After that, the treatment JP4 had the highest amount of dry and fresh weight and the highest number of fruits. The mean of dry and fresh weight of fruit in these two treatments was significantly different at 0.05; however, the number of fruits in these two treatments was not significantly different. In all other treatments, the dry and fresh weight and the number of fruits were significantly low. The lowest number of fruits and the lowest dry and fresh weight was seen in the treatment P4P2 (Table 3). Accordingly, using leachate for two parts of root media in static and dynamic systems led to a reduction in plant growth. In JP4, the number of fruits had a significant difference with the treatment which was in normal condition (JJ), the fresh weight of fruit in this treatment, which is very important in terms of economy

Table 3. The number of fruits, fruits fresh weight, fruits dry weight, water used, crop per drop of tomato as affected by the treatments*.

Features of treatment	Fruit dry weight (g)	Fruit fresh weight (g)	Number of fruits	Water used (L)	Crop per drop (g/L)
JJ	51.44^{a}	538.44^{a}	19.4^{a}	12.59^{a}	42.8^{a}
JP4	42.15^{b}	402.45^{b}	18.7^{a}	11.25^{ab}	35.8^{b}
WP4	14.30^{c}	188.98^{c}	8.7^{b}	10.26^{abc}	18.5^{c}
P4P2	10.17^{c}	103.97^{d}	6.4^{c}	8.57^{c}	12.7^{c}
P2P2	12.91^{c}	167.13^{dc}	8.7^{b}	11.48^{ab}	15.5^{c}
P4P4	11.68^{c}	132.75^{dc}	7.7^{b}	9.03^{bc}	15.4^{c}
PPt	11.89^{c}	143.49^{dc}	7.0^{bc}	10.61^{abc}	13.9^{c}

*: In each column, means with the same letter are not significantly different.

although had a significant difference with the treatment JJ, the efficiency was 25.3% lower than normal condition (JJ). In the case of a 50% reduction of nutrient solution for a 25% reduction of the crop, economically it would be cost-effective and therefore, this treatment is suggested. In previous studies, it was reported that in low levels of salinity, the reason for the reduction is the reduction of fruit weight, but in high levels of salinity, the reduction in the number of fruits can cause a reduction in efficiency (Cuartero and Fernandez-Munoz, 1999).

Crop per drop (CPD)

The results showed that the volume of water used in the two treatments in which leachate was used for two sides of root culture (P4P2, P4P4) was lowest compared with other treatments. The treatment JJ had the highest level of water use. That is, in all treatments the existence of leachate and an increase in the amount of salinity of culture had reduced water consumption. With increasing salinity in root media culture, due to physiological and morphological changes in the root, water consumption is reduced by the root of tomato (Aranda et al., 2001). Reduction in leaves (Aranda et al., 2001) and increase in Abscisic Acid hormone in plants (Kidra et al., 2004) are among the mechanisms that result in efficiency in water consumption (Tardieu et al., 2010). In this study, the dynamic system reduced the toxicity of sodium, which had been considered a limitation in previous studies about the unequal distribution of salinity in root media (Koushafar et al., 2011). Although in the present study, a significant reduction of water consumption was seen in treatments in which leachate was used, this reduction should be investigated in terms of efficiency because the growth and performance of the plants were reduced simultaneously. In the treatment JJ, the highest mean of CPD was seen (42.8 g/L) (Table 3). After that, the highest CPD was seen in the treatment of JP4. In other treatments, due to leachate limitation, CPD was low. The CPD in treatments of WP4, P4P2, P2P2, P4P4, and PPt, compared with the treatment JJ, decreased 56.8, 70.3, 63.8, 64 and 67.5% respectively. The results showed that the main reason for this reduction was due to a reduction in efficiency, not water consumption (Table 3). In contrast to previous studies (Koushafar et al., 2011), in a split-root system with sodium chloride solution which caused an increase in CPD, in this study using leachate or leachate with water in unequal distribution of salinity didn't result in CPD. In the treatment JP4, the reduction of CPD was 16.4%, where it was the only treatment that the CPD didn't have much reduction compared with the treatment in normal condition (JJ). In this study, the CPD of tomato was reduced by 16.4, and 50% of the nutrient solution was substituted with leachate, so 5.6 liters of the consumption of nutrient solution was reduced. Therefore, this needs more economic study. Since one of the objectives of this study was substituting leachate with a nutrient solution, in all treatments in which leachate was used without a nutrient solution both fruit yield and CPD reduced significantly. So, these treatments are not acceptable and only the treatment (JP4) with a low reduction in performance and CPD is suggested. According to the fact that CPD was introduced with the idea of increasing output (Meredith et al., 2006) in terms of water consumption, and based on the fact that efficiency indicators can be defined according to different views in this study, the treatments JJ and JP4 can be compared if we change CPD to crop per nutrient solution according to the economical valve of nutrient solution. In this case, the crop per nutrient solution of these two treatments were 42.8 and 71.6 g/L, respectively. In the treatment in which half of the root media leachate was used instead of nutrient solution (JP4), the indicator of crop per nutrient solution increased by 18.9%. So, the treatment JP4, when in the dynamic unequal distribution of salinity in root culture, leachate was used for one side of the root culture, is a suitable treatment for increasing efficiency, however, economic aspects should be taken into account.

4. Conclusion

The results of this study showed the lowest growth, yield, and the CPD of tomato were observed at the treatments where all parts of the roots were exposed to vermicompost leachate, but the application of this leachate in combination with a nutrient solution in the split-root media culture reduced destructive effects of leachate on growth and performance of tomato. The growth, yield, and CPD of tomato plants were greater in the split root hydroponic systems where vermicompost leachate was applied at one part of the media roots and the other part was immersed in the nutrient solution in comparison with the other treatments, so the vermicompost leachate can be used for tomato planting, and this system is suggested. Therefore, using the vermicompost leachate without using the nutrient solution in both uniform and unequal systems of root media, severely reduced the growth and crop per drop of tomato, and therefore, it is not recommended.

Ethical Approval
This manuscript does not report on or involve the use of any animal or human data or tissue. So the ethical approval is not applicable.

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Authors Contributions
The authors confirm the study conception and design. Data collection, analysis and interpretation of results, and draft manuscript preparation: M. Khoshafar; edit English, standardization of references, and preparation of graphical abstract: MR Fadaei Tehrani. The final version of the manuscript was approved by all authors.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests
The authors declare that there are no conflicts of interest associated with this study.

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