Res. Crop. **23** (1) : 156-162 (2022)
With eight figures
Printed in India
DOI : 10.31830/2348-7542.2022.022

Effect of different soilless agriculture methods on irrigation water saving and growth of lettuce (*Lactuca sativa*)

MUNQEZ J. Y. SHTAYA[1,*] AND TAWFIQ QUBBAJ[1]

[1]*Department of Plant Production and Protection*
Faculty of Agriculture and Veterinary Medicine
An-Najah National University, P.O. Box 7, Nablus, Palestine
(e-mail : mshtaya@najah.edu)

(Received : January 04, 2022/Accepted : February 18, 2022)

ABSTRACT

Environmental stresses such as low soil moisture and soil nutrient deficiency are among the main causes of low crop productivity in arid and semi-arid regions. Soilless cultivation is intensively used in protected agriculture to improve control over the growing environment and avoid uncertainties in the soil's water and nutrient status, leading to better result in water use efficiency, while maintaining the quality of the yield. Therefore, this study was conducted at the Faculty of Agriculture, An Najah University, Palestine, during 2016-17 growing season to investigate the effects of three soilless culture systems compared to agricultural soil growing media on yield and water use efficiency of lettuce crop under greenhouse cultivation. Four different growing media were investigated; pure soil serves as a control, pure volcanic tuff (VT), peat moss perlite mixture (2:1 v/v) and the nutrient film technique (NFT) (hydroponic) and their effect on the growth and productivity of lettuce were monitored. Results showed no significant differences in lettuce crop fresh weight and total fresh weight produced per unit area (m^2) within the different growing media tested. In contrast, the different growing media significantly influenced the water use efficiency (WUE) values. Peat moss-perlite mixture and the nutrient film technique (NFT) media resulted in the highest WUE and can save water remarkably, with an irrigated water saved ranging from 94 to 123%, respectively. Overall, results suggest that the NFT hydroponic system is the most efficient system for water-saving and water use efficiency.

Key words : Hydroponics, lettuce, nutrient film technique, water use efficiency

INTRODUCTION

Water is the most limiting factor for the expansion of agriculture in Palestine. Most of the cultivated lands in Palestine are rain-fed, and only 10% are irrigated (PCBS, 2020). Only 250 GL of water is available annually to Palestinian people, and 70% of this is used in the Agricultural sector (MoA, 2020). Significant reductions in water availability for irrigation use especially in the coastal and eastern aquifers have increased the importance of implementation of water conservation practices in agriculture. Agricultural practices such as the use of plastic mulch, drip irrigation and quantitative irrigation scheduling are common in Palestine. They provide growers with a viable option to reduce crop water requirements and thus conserve water resources, especially when compared to traditional irrigation methods (Rahil and Qanadillo, 2015). Conventional agricultural practices can cause a wide range of negative impacts on the environment. "Conventional" or "modern industrial agriculture" has been historically defined as the practice of growing crops in soil, in the open air, with irrigation, and the active application of nutrients, pesticides, and herbicide (Barbosa *et al.*, 2015). Water conservation and efficient water use can significantly improve local farming systems. An effective alternative suggested by local communities and governments is soilless in the greenhouse, which reduces crops' need for water. Water-efficient technologies could help communities to optimize the use of limited water resources. The effective soilless growing medium must have a physical structure that creates an appropriate balance of air and water for healthy root development. This balance must be maintained over an entire crop production cycle, which can last from several weeks to more than a year. Growing medium structure is determined by the size, shape, texture and physical arrangement of the particles from which it is composed (Bilderback *et al*., 2005). Chemical properties as pH, electrical conductivity, cation exchange capacity and nutrient availability have been measured across a diverse range of growing media and are extensively reviewed (Samarakoon *et al*., 2020). Biological properties are also an important consideration for organic materials, as they can have significant impacts on growing medium performance (Walters and Currey, 2018). Soilless Agriculture leads to faster growth and an extreme decrease in water and nutrient use. Hydroponics typically uses at least 90% less water than soil-based methods. So much of the water and nutrients are wasted on traditional outdoor soil farms because only a small portion of it makes it to the roots, and the rest ends up in the local water supply.

Hydroponics culture has many advantages such as increased yield, healthy and uniform products, conservation of land, better protection, control of environmental pollution and labour reduction (Makhadmeh *et al*., 2017; Samarakoon *et al*., 2020). The greenhouse systems that use hydroponics are considered to be superior to field production systems in terms of water and nutrient use efficiencies (Grewal *et al*., 2011; Al-Tawaha *et al*., 2016; Al-Tawaha *et al*., 2018; Walters *et al*., 2020). A Liquid-medium system is a type of soilless culture and differentiated from solid-medium systems by method of operation. Liquid systems are generally closed circuits and the nutrient solution is recirculated from a supply reservoir either continuously or intermittently for days or weeks. In hydroponics, there are several growing systems used such as; nutrient film technique (NFT), deep flow technique (DFT), dynamic root floating technique (DRFT) and substrate culture (Koohakan *et al*., 2008). However, the most widely used method to grow leafy greens is NFT (Tabaglio *et al*., 2020; Wibisono and Kristyawan, 2021). The NFT growing system consists of a series of narrow channels through which nutrient solution is recirculated from a supply tank. A plumbing system of plastic pipes and a submersible pump in the tank are the basic components of the system (Shanmugabhavatharani *et al*., 2021). However, farmers in Palestine are still not commonly applying these modern cultivation systems (MoA, 2020). Therefore, the present study was carried out to assess the effects of soilless agriculture on the yield of lettuce and to estimate the amount of irrigation water that could be saved from using soilless methods.

MATERIALS AND METHODS

Experiment Layout

The experiment was carried out at the Faculty of Agriculture and Veterinary Medicine farm, Tulkarm, (32.31519° N, 35.02033° W and altitude of 75 m above sea-level) under controlled greenhouse conditions during the period extending from the 1st of November to the 10th of December 2016 (40 days). Four different growing methods were used: 1) pure soil (air-dried and sieved through a 2 mm mesh), 2) pure volcanic tuff (VT), 3) peat moss perlite mixture (2:1 v/v) and 4) closed nutrient film technique (NFT). These four growing methods are the most used methods for lettuce growing. The experimental design was a completely randomized design (CRD) with four replicates and each replicate was represented by 30 plants. In the pure soil and peat-moss perlite mixture treatments, lettuce plants were grown in separated pots (Sealed plastic pots, 26 cm in diameter and 40 cm deep, one plant per pot). In the NFT (closed), each replicate consisted of 3 independent 4 m long white PVC tubes (4″ diameter). In the volcanic tuff treatment (open system), each replicate consisted of 1 independent 12 m long PVC plastic ground container (40 cm width × 20 cm height) filled with volcanic tuff.

Nutrition Solution and Irrigation System Used Under Soilless System

The amount of irrigation water to be applied in the soil (control) and peat moss treatments, was measured as traditionally applied by the farmers in the experiment area and according to plant observation and growth development stages. Pots were irrigated once every other day. For the volcanic tuff, irrigation water was applied five times per day for 10 min each.

All treatments received the same amount of fertilizers. Compound liquid fertilizer (6:6:6) at a rate of 22 and 42 litter per 1000 square meters was applied at three days intervals during the first and second growth stages respectively (the two growth stages lasted for 35 days from transplanting day). Also, another liquid fertilizer (5:3:8) at a rate of 48 L per 1000 square meters was applied during the third growth stage which lasted for 10 days. The amount of compound fertilizers was applied according to the NPK requirement of lettuce crop during the growth periods as given in Table 1.

Table 1. Nutrient requirements of lettuce crop cultivated in the greenhouse (MoA, 2020)

Plant growth stages	Nutrient requirement (kg/ha)		
	N	P_2O_5	K_2O
Transplanting (14 days)	110	110	110
15 - 35 days	140	140	140
36 - 45 days	280	170	440

Parameters Recorded

At the end of the experiment, plants were cut down to the soil surface and plant fresh weight was determined. The amount of water added was recorded from the beginning to the end of the experiment to estimate the amount of irrigation water saved using the following formula (Owais *et al.*, 2013):

$$IWS\ (\%) = \frac{WPST - WT}{WPST} \times 100$$

Where, IWS is irrigated water saved in percentage, WPST is the amount of water applied to pure soil treatment (the control) in litre and WT is water applied to treatments in litre.

Water use efficiency (WUE) can be defined as the units of a crop produced from each unit of water added to the growing medium (*e.g.,* dry weight (g) per kg water). The more crop yield produced per unit of water, the greater is the WUE. WUE was estimated for each media by calculating the ratio between the dry total plant biomass produced in g and the total kg water added during the experiment.

Statistical Analysis

Analysis of variance (ANOVA) was conducted using the PROC GLM procedure of SAS/STAT software, version 9.0 for Windows (SAS institute 2002). Multiple comparisons among pairs of lines were performed using the Duncan test.

RESULTS AND DISCUSSION

Impact of Growing Media on Lettuce Yield

The fresh areal parts are the main component of interest of lettuce. Thus, the plant must produce the maximum fresh weight of leaves. The results of the impact of different growing media on lettuce yield parameters; fresh weight and stem diameters are shown in Figs. 1, 2 and 3. The highest plant fresh weight and total yield per unit area (m^2) were found in Tuff growing media, however, it was not significantly different when compared to other tested growing media ($P \leq 0.05$).

Mixtures of peat-moss and perlite gave the lowest values with an average of 650 g for head fresh weight per plant, compared to other growing media used. Although the head biomass (g/ plant) had higher values (810 g) in volcanic tuff growing media, however, it had no statistically significant differences nor economic feasibility as the lettuce is sold by unit and not by weight (g).

Stem diameter at the base of the head after trimming was also measured as yield parameters. The stem diameter was greater in the plants grown in Tuff but not significantly different compared to stem diameters of plants grown in NFT (Fig. 3).

These results of no statistically

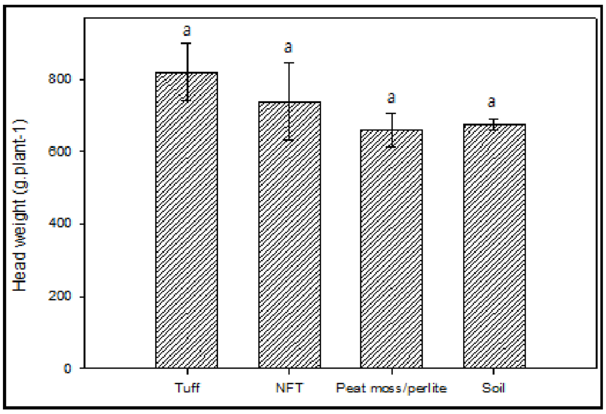

Fig. 1. Effect of different growing media on plant fresh weight (g). Results labeled same letters are not significantly different at $P \leq 0.05$.

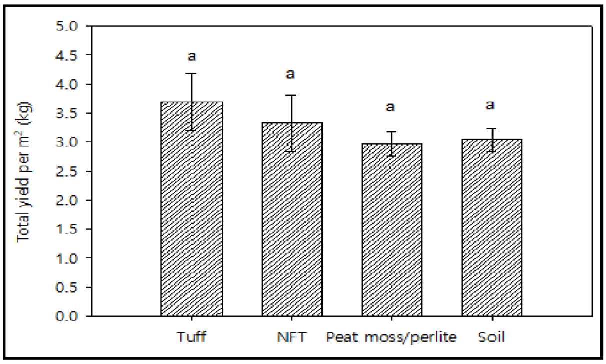

Fig. 2. Effect of different growing media on total yield per m^2 (kg). Results labeled ns are not significantly different at $P \leq 0.05$.

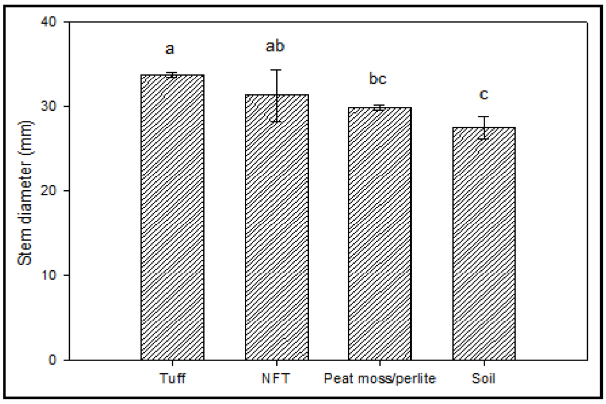

Fig. 3. Effect of different growing media on plant stem diameter (mm). Results labeled with different letters are significantly different at $P \leq 0.05$.

significant impact nor economic feasibility differences of using different growing media cultures on lettuce total plant biomass are in agreement with previous findings of Makhadmeh *et al.* (2017) and Shanmugabhavatharani *et al.* (2021) carried out on lettuce, tomato, and mint crops respectively. Makhadmeh *et al.* (2017) found the lettuce planting density and growth medium resulted in a higher head mass (g) when using Tuff: peat-moss mixture growing media with a planting density of 16 plants/m^2.

The fine particle substrate as peat-moss and perlite are characterized as a fine particle substrate (relatively low air-filled porosity), oxygen deficiency in root rhizosphere might occur when plants exhibit high growth rates and intensive root respiration (Jayasinghe, 20212; Al-Ajlouni *et al.*, 2017). Therefore, the substrate's particle size distribution is important as it determines the pore space, gas exchange and water retention capacity which improve the plant's growth. Accordingly, our results of no significant differences in lettuce head fresh weight per plant cultivated either in larger particles substances (tuff) or fine particle substrate (mixtures of peat-moss and perlite) can be attributed to the excessive aeration and inadequate water to be retained in tuff, whereas in the fine particles, the pores can be clogged which reduces the porosity aeration.

The different growing media were found to significantly affect the dry weight (Fig. 4) but did not significantly alter the total fresh weight of the shoots of lettuce (Fig. 1).

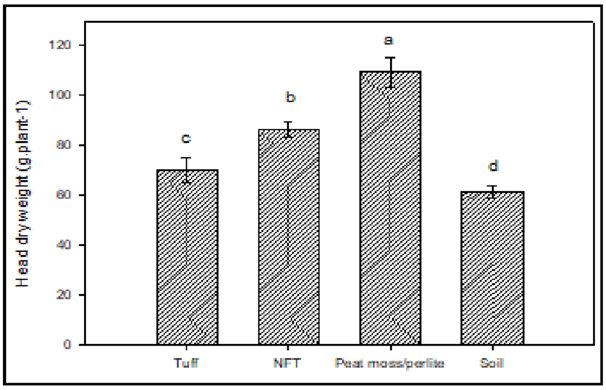

Fig. 4. Effect of different growing media on plant dry weight (g). Results labeled with different letters are significantly different at $P \leq 0.05$.

Although there was no significant effect of different growing media on fresh weight, the total dry weight of the shoots of lettuce was significantly decreased in tuff and soil growing media.

The decline in dry weight contrasted with an increased fresh weight of the shoots in Tuff and soil-growing media suggests continued absorption of water by the plant without its normal loss by transpiration (Tátrai *et al.*, 2016). The fresh weight to dry weight ratio (FW: DW) which can be used as an index of water content and leaf succulence (Castrillo *et al.*, 2005) has been determined. A contrasting pattern of the effect of different growing media on fresh weight to dry weight ratio compared to dry matter was found (Fig. 5). Although there are no significant differences of the growing media on fresh weight has been recorded.

The fresh weight to dry weight ratio is related to both species and environment (Castrillo *et al.*, 2005). While in the current research the same lettuce plants are used

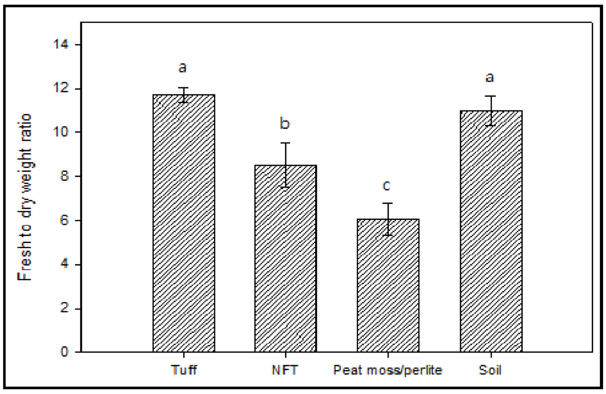

Fig. 5. Effect of different growing media on fresh weight: dry weight ratio (FW: DW). Results labelled with different letters are significantly different at P ≤ 0.05.

under the same environmental condition except for the different growing media and the water availability. The significant increase in the fresh weight to dry weight ratio dry weight of lettuce grown in tuff and soil growing media could be attributed to the absorption of water by the plant without its normal loss by transpiration (Tátrai *et al.*, 2016). Although the increase of water content in the plant cell leads to an increased value of fresh weight (Castrillo *et al.*, 2005). But in leafy crops like lettuce, the higher the water content is, the softer and easier it is to lose water of leaf tissue. Therefore, it will be hard to maintain the freshness of lettuce leaves during postharvest handling and storage.

Effect of Media on Total Irrigation Water Used, Agricultural Water-Saving and Water Use Efficiency (WUE)

The amount of water added (m^3) in each media and the amount of water saved (%) in each media compared to pure soil (control) are presented in Figs. 6 and 7, respectively. The total irrigation water applied during the experimental period (40 days) was found to be significantly affected by the growing media used (Fig. 6). The highest water used is in tuff and agricultural pure soil with no significant difference among the two growing media in terms of water requirements for lettuce crop vegetative growth. While using the nutrient film technique (NFT) was found to significantly reduce the irrigated water for lettuce crop vegetative growth drastically, compared to both tuff and soil growing media. During the growing cycle, the water use in soil (30 L/m^2) was significantly higher compared with the water requirements of plants grown respectively in NFT (13 L/m^2) and peat-moss/perlite (15 L/m^2) (Fig. 6). The high use of water in soil culture could be attributed to the water losses by infiltration over the root zone, while the difference between soilless treatments was related to the physical properties and in particular to the content of easily available water in the media.

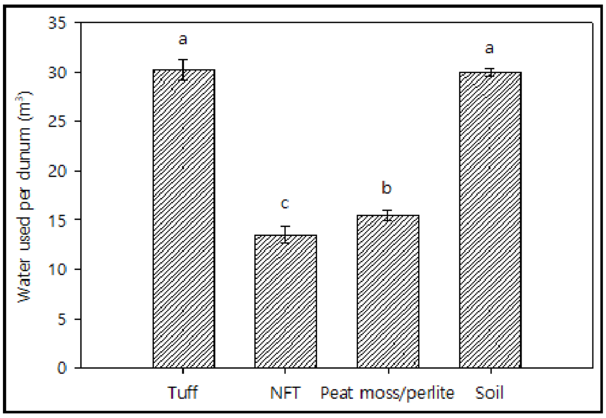

Fig. 6. Effect of different growing media on total water used per dunum (m3). Results labelled with different letters are significantly different at P ≤ 0.05.

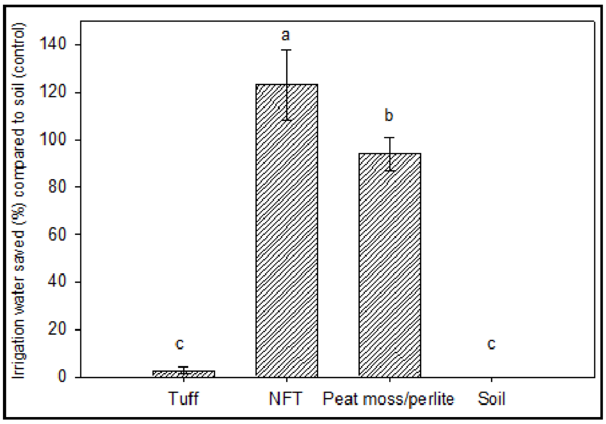

Fig. 7. Effect of different growing media on the amount of water saved in media compared to pure soil. Results labeled by the same letters are not significantly different at P ≤ 0.05.

Results also showed that peat moss-perlite and NFT can act as water saving. The amount of irrigated water saved ranged from 94 to 123%, respectively compared to pure soil (Fig. 7). The nutrient film technique (NFT) maximizes water-use efficiency by reducing water loss due to drainage and run-off, by recycling all the water and nutrients not utilized by the plants. These results are in agreement with Agung and Yuliando (2015). In addition, the lettuce plant has a shallow root system and a limited capacity to use water stored deep in the soil or growing media, thus its high susceptibility to water stress. Therefore, the soil should be kept moist at all times during the growth stages (Molina-Montenegro *et al.*, 2011).

Water use efficiency (WUE) was calculated for each treatment in terms of a gram (g) of total fresh yield per kilogram (litter) of water added to the lettuce crop all over the growing season. The yield water use efficiency calculated on a fresh weight basis ranged from 34 kg of fresh product per m^3 of water (soil as growth media) to 121 kg of fresh product per m^3 of water (NFT) (Fig. 7). The highest WUE values were observed with the NFT compared to different growing media tested.

In summary, there were no significant differences between different growing media tested in fresh weight per plant (Fig. 1), while fresh fruit weight per unit of water use was more distinct in NFT soilless in comparison to the soil culture (Fig. 8). This increase in water use efficiency has been described as an efficient strategy to manage the negative effects of water stress in crops (Molina-Montenegro *et al.*, 2011). It was clear that the yield-related water use efficiency can be increased by reducing the water loss due to drainage and run-off, by recycling the nutrient solution. Therefore, the foregoing results demonstrated that growers may improve, yield, water requirement and water use efficiency by switching from soil to soilless culture growing system as NFT.

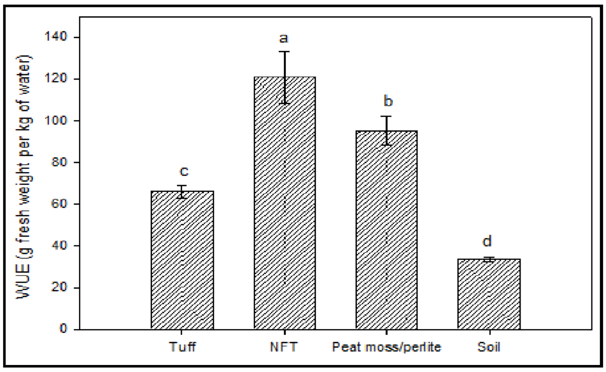

Fig. 8. Effect of different growing media on water use efficiency (WUE). Results labeled by the same letters are not significantly different at P ≤ 0.05.

CONCLUSIONS

The results of the present study show that the different soilless agricultural systems used do not have significant effects on the growth and productivity of lettuce. However, significant differences were observed in the water use efficiency of the systems. Systems such as the NFT, which can increase the efficiency of water usage while maintaining product quality, should be more commonly implemented. Overall results suggest that the NFT hydroponic system is the most efficient system at both water-saving and water use efficiency, therefore increasing water productivity which is an important element in improved water management in the semi-arid area like Palestine for ensuring sustainable agriculture, food security and a healthy ecosystem functioning. The effect of tuff on WUE and water-saving could be improved by reusing the leached water through a closed system or by reusing it for irrigating another crop. Peat moss perlite mixture is efficient but could be considered as the most expensive method in the long term since it should be changed frequently.

ACKNOWLEDGMENTS

This research was supported by An-Najah National University. The author gratefully acknowledges the excellent technical assistance by the technical team of the experimental farm of the Faculty of Agriculture, An-Najah National University.

REFERENCES

Agung, P. P. and Yuliando, H. (2015). Soilless culture system to support water use efficiency and product quality: a review. *Agric. Agric. Sci. Proc.* **3** : 283-88.

Al-Ajlouni, M. G., Ayad, J. Y. and Othman, Y. A. (2017). Particle size of volcanic tuff improves shoot growth and flower quality of Asiatic hybrid lily using soilless culture. *HortTechnol.* **27** : 223-27.

Al-Tawaha, A., Al-Karaki, G. and Massadeh, A. (2016). Effects of planting density and cutting height on herbage and water use efficiency of thyme (*Origanum syriacum* L.) grown under protected soilless and open field conditions. *Res. Crop.* **17** : 118-28.

Al-Tawaha, A. R., Al-Karaki, G., Al-Tawaha, A.R., Sirajuddin, S. N., Makhadmeh, I., Wahab,

P. E. M., Youssef, R. A., Al Sultan, W. and Massadeh, A. (2018). Effect of water flow rate on quantity and quality of lettuce (*Lactuca sativa* L.) in nutrient film technique (NFT) under hydroponics conditions. *Bulg. J. Agric. Sci.* **24** : 793-800.

Barbosa, G. L., Gadelha, F. D. A., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G. M. and Halden, R. U. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. *Int. J. Environ. Res. Public Health* **12** : 6879-891.

Bilderback, T. E., Warren, S. L., Owen, J. S. and Albano, J. P. (2005). Healthy substrates need physicals too. *HortTechnol.* **15** : 747-51.

Castrillo, M., Vizcaíno, D., Moreno, E. and Latorraca, Z. (2005). Specific leaf mass, fresh: dry weight ratio, sugar and protein contents in species of Lamiaceae from different light environments. *Rev. Biol. Trop.* **53** : 23-28.

Grewal, H. S., Maheshwari, B. and Parks, S. E. (2011). Water and nutrient use efficiency of a low-cost hydroponic greenhouse for a cucumber crop: An Australian case study. *Agr. Water Manage.* **98** : 841-46.

Jayasinghe, G. Y. (2012). Synthetic soil aggregates as a potting medium for ornamental plant production. *J. Plant Nutr.* **35** : 1441-456.

Koohakan, P., Jeanaksorn, T. and Nuntagij, I. (2008). Major diseases of lettuce grown by commercial nutrient fi lm technique in Thailand. *Curr. Appl. Sci. Technol.* **8** : 56-56.

Makhadmeh, I. M., Al-Tawaha, A., Edaroyati, P., Al-Karaki, G., Tawaha, A. R. A. and Hassan, S. A. (2017). Effects of different growth media and planting densities on growth of lettuce grown in a closed soilless system. *Res. Crop.* **18** : 294-98.

MoA (2020). Annual report, 2020. Ministry of Agriculture, general directorate of extension services. pp. 40.

Molina-Montenegro, M. A., Zurita-Silva, A. and Oses, R. (2011). Effect of water availability on physiological performance and lettuce crop yield (*Lactuca sativa*). *Int. J. Agr. Nat. Resour.* **38** : 65-74.

Owais, S. J., Abdel-Ghani, A. H., Ghrair, A. M., Al-Dalain, S. A. and Almajali, N. (2013). Effect of natural Jordanian volcanic tuff on growth, irrigation water saving and leaves mineral content of salvia officinalis. *Jordan J. Agr. Sci.* **9** : 439-56.

PCBS (2020). Agricultural census in the Palestinian Territory, 2020. Palestinian Central Bureau of Statistics.

Rahil, M. H. and Qanadillo, A. (2015). Effects of different irrigation regimes on yield and water use efficiency of cucumber crop. *Agr. Water Manage.* **148** : 10-15.

Samarakoon, U., Palmer, J., Ling, P. and Altland, J. (2020). Effects of electrical conductivity, pH, and foliar application of calcium chloride on yield and tipburn of *Lactuca sativa* grown using the nutrient–film technique. *HortSci.* **55** : 1265-271.

Shanmugabhavatharani, R., Priya, R. S., Kaleeswari, R. K. and Sankari, A. (2021). Performance assessment of mint on growth and yield attributes supplied with three nutrient combinations under two modified nutrient film technique (NFT). *The Pharma Inno. J.* **10** : 17-22.

Tabaglio, V., Boselli, R., Fiorini, A., Ganimede, C., Beccari, P., Santelli, S. and Nervo, G. (2020). Reducing nitrate accumulation and fertilizer use in lettuce with modified intermittent nutrient film technique (NFT) system. *Agronomy* **10** : doi: 10.3390/agronomy10081208

Tátrai, Z. A., Sanoubar, R., Pluhár, Z., Mancarella, S., Orsini, F. and Gianquinto, G. (2016). Morphological and physiological plant responses to drought stress in Thymus citriodorus. Int. J. Agron. 2016. doi.org/10.1155/2016/4165750.

Walters, K. J. and Currey, C. J. (2018). Effects of nutrient solution concentration and daily light integral on growth and nutrient concentration of several basil species in hydroponic production. *HortSci.* **53** : 1319-325.

Walters, K. J., Behe, B. K., Currey, C. J. and Lopez, R. G. (2020). Historical, current, and future perspectives for controlled environment hydroponic food crop production in the United States. *HortSci.* **55** : 758-67.

Wibisono, V. and Kristyawan, Y. (2021). An efficient technique for automation of the NFT (Nutrient Film Technique) hydroponic system using Arduino. *Int. J. Artifi. Intel. Robo.* **3** : 44-49.