Palestine Technical University Research Journal, 2022, 10(4), 11-24

Impact of Heating Irrigation Water on Growth and Development of Cucumber Plants Cultivated in Winter Season

تأثير تسخين مياه الري على نمو وتطور نبات الخيار المزروع في موسم الشتاء

Mahmoud Rahil[1*], Abdelrahman Bani-Odeh[2], Bassmah Bushnaq[2], Mays Namoura[2]

محمود رحيل[1*]، عبدالرحمن بني عودة[2]، بسمة بشناق[2]، ميس نمورة[2]

[1,2]Department of Environment and Sustainable Agriculture, Palestine Technical University Kadoorie, Tulkarm, Palestine

[1,2]قسم البيئة والزراعة المستدامة، جامعة فلسطين التقنية - خضوري، طولكرم، فلسطين

Received: 31/12/2021 **Accepted: 28/03/2022** **Published: 30/09/2022**

Abstract: A field study was conducted inside the greenhouse of Palestine Technical University Kadoorie, Tulkarm, Palestine, in February 2018. The main aim of this study was to investigate the season. Cucumber seedlings were cultivated in two rows: one covered with mulch and the other one without mulch. Irrigation water was heated for 30, 35 and 45 ºC and applied to the plants during each irrigation event. Tab water without heating (25 ºC) was used as control. Soil samples were taken before sowing to analyze the physiochemical properties of the soil at initial conditions. Soil moisture content and microbial activity were monitored during the growing season. Plant length, fruit number per plant, total yield and chlorophyll content was measured during the growing season. The results of soil analysis indicated that the soil was clay texture and the electrical conductivity (1 dS/m) was suitable for cucumber cultivation. The cucumber plants irrigated with irrigation water temperature of (35 ºC) produced the highest plant length, yield production and fruit number in both treatments with and without mulch compared to the other irrigation water temperatures. Furthermore, in plants without mulch, heating irrigation water temperature up to (45 ºC) produced the highest chlorophyll content, followed by irrigation water temperature of (35 ºC). It was found that heating irrigation water enhanced the microbial activity of the soil mainly for the treatment irrigated with water temperature of (45 ºC) without mulch. It could be concluded that heating irrigation water up to (35 ºC) can improve plant growth and development of cucumber plants as well as increase yield production with major improvements under mulch cultivation.

Keywords: Water temperature, Yield production, Chlorophyll content, Soil moisture, Microbial activity.

المستخلص: تم اجراء دراسة ميدانية داخل البيت البلاستيكي لجامعة فلسطين التقنية خضوري، طولكرم، فلسطين، في شهر شباط 2018. الهدف الرئيسي من هذه الدراسة هو دراسة مدى تأثير تسخين مياه الري على نمو وتطور محصول الخيار خلال موسم الشتاء. تم زراعة اشتال الخيار في صفين: صف مع غطاء بلاستيكي والآخر بدون غطاء. تم تسخين مياه الري على درجة حرارة 30 و 35 و 45 درجة مئوية واستخدامها لري النباتات. تم استخدام مياه

*البريد الإلكتروني للباحث الرئيسي: mrahail@ptuk.edu.ps

الري (25 درجة مئوية) بدون تسخين كشاهد. تم أخذ عينات من التربة قبل الزراعة لتحليل الخصائص الفيزيائية والكيميائية للتربة لدراسة حالة التربة المبدئية. خلال موسم نمو النبات تم مراقبة حالة رطوبة التربة ونشاط احياء التربة الدقيقة. تم قياس طول النبات وعدد الثمار لكل نبات ومعدل الانتاج ومحتوى الكلوروفيل خلال موسم النمو. نتائج تحليل التربة بينت ان التربة ذات قوام طيني، اما التوصيل الكهربائي للتربة (1 dS/m) كان مناسباً لزراعة محصول الخيار. أشارت نتائج هذه الدراسة إلى أن نباتات الخيار المروية بمياه حرارتها 35 درجة مئوية أعطت أعلى طول للنبات وأعلى إنتاجية وأعلى عدد ثمار في حالة التغطية او بدون تغطية مقارنة مع باقي درجات حرارة مياه الري. علاوة على ذلك فان تسخين مياه الري لغاية 45 درجة مئوية اعطت اعلى محتوى كلوروفيل يتبعها النباتات المروية بمياه ري حرارتها 35 درجة مئوية خاصة في حالة التغطية بالبلاستيك. كذلك اظهرت النتائج ان تسخين مياه الري ادت الى تحفيز نشاط احياء التربة الدقيقة خاصة في المعاملات المروية بمياه درجة حرارتها 45 درجة مئوية في حالة عدم التغطية. نستنتج أن رفع درجة حرارة مياه الري إلى 35 درجة مئوية يمكن أن تعمل على تحسين نمو وتطوير نباتات الخيار بالإضافة إلى زيادة الإنتاج مع تحسينات كبيرة في حالة الزراعة مع تغطية.

الكلمات المفتاحية: حرارة المياه، الانتاجية ، محتوى الكلوروفيل، رطوبة التربة، نشاط الاحياء الدقيقة.

INTRODUCTION:

Cucumber is one of the major vegetable crops cultivated in Palestine under greenhouse conditions, which constitutes 14.4% of the total area planted with vegetable crops in the Palestinian Territories. It is a subtropical vegetable crop that grows successfully under conditions of high light, humidity, soil moisture, temperature and fertilizers in greenhouse (El-Aidy et al., 2007). Lee et al. (2004) found that root pressure, hydraulic conductivity and nutrients active transport were seriously reduced when roots were exposed to low temperature during cold seasons. So, nutrient uptake could be inhibited by low root zoon temperature (Peng and Dang, 2003).

Soil temperature is considered as an important factor that has impacts on vegetative growth and development of the plant during different stages of crop growth (Roh and Hong, 2007). Optimum soil temperature is necessary for improving the vegetative growth of the plant (Summerfield et al., 1989). High soil temperatures or very low temperature may result in detrimental effects to different metabolic reactions in plant such as chlorophyll pigments, nutrient uptake, as well as photosynthetic reaction (Markwell et al., 1986). Several studies have indicated that at low soil temperatures the chlorophyll content, nutrient uptake and photosynthetic reaction are negatively affected. Furthermore, at ideal temperature levels the rate of plant metabolism is improved which in turn influence the whole plant vegetative growth (Frantz et al., 2004; Kurek et al., 2007).

The temperature surrounding the plant environment impacts the rate of plant growth and development. Each crop variety has its specific range of temperature ranging from optimum, maximum, and minimum values. Hatfield et al. (2011) summarized different temperature values for different plants like grain and fruit crops. It has been reported that temperature regimes impact plant in different manner and plant can adapt well under certain temperature (Bubel, 2007). It was found that when water temperature falls down below the optimum values, different modifications to the plant growth environment are needed for improving crop growth and development (Santarius, 2004). This can be achieved by increasing the temperature of irrigation water or heating the plant growth medium to the suitable temperature to improve crop growth (Rosik-Dulewska and Grabda, 2002). In a field experiment, heating of irrigation water used in a variety of crops cultivated under greenhouse conditions, had induced the plant growth and development (Kozai, 2006; Sethi and Sharma, 2007).

During winter season when temperature is very low, heat is important to enhance plant development (Moorby and Graves, 1980; Sethi and Sharma, 2007). Increasing the temperature of the plant growth media has been tested in several experiments to enhance plant growth and development (Moorby and Graves, 1980). Moreover, root heating of pears, apple and plum rootstocks resulted in successful enhancement of rooting depth and distribution of the roots (Bite and Lepsis, 2004). In addition to that, heating the plant growth media has also contributed to energy savings compared to heating the whole nurseries (Laubscher and Ndakidemi, 2008).

In hydroponic culture, it was found that the temperature of root zone might be improved by heating the water solution and thus enhancing the temperature needed for improving vegetative growth of the plants (Calatayud et al., 2008; Nxawe et al., 2010). Enhancing the temperature of water solution in the hydroponic system can improve water absorption and plant nutrient uptakes, enhance metabolic reactions and hence increasing vegetative growth and development (Dong et al., 2001). In addition to that, the increased temperature of water solution increased the solubility of nutrient elements and the plant uptake since the rate of nutrients dissolution increased with increasing the temperature of the solution (Moorby and Graves, 1980; Xu and Huang, 2006). Yan et al. (2013) and Sakamoto and Suzuki (2015), observed that the temperature of the root-zone also impacts the chemical composition of plant tissues. Numerous field studies carried on different plant species indicated that the plant growth and development is greatly influenced by modifying the temperature of the root zone (Diaz-Perez et al., 2007; Nxawe et al., 2009).

It has been observed that the chemical, physical and biological reactions of the soil may be influenced by the soil temperature which in turn impacts nutrient assimilation and hence impact water and nutrients uptake efficiency by the plant roots (Hussain and Maqsood, 2011). Clarkson et al. (1992) found that the rate of plant nutrients uptake depends mainly on soil temperature; even in a small change in soil temperature may influence nutrient dissolution and uptake. It was found that the rate of organic matter mineralization is highly influenced by the soil temperature and enhance availability of nutrient element from the decomposition of soil organic matter (Davidson and Janssens, 2006; Onwuka, 2016). Furthermore, soil moisture content together with soil temperature are the major environmental factors influencing the activity of soil microorganism (Paul and Clark, 1996). Because of global warming, the impact of soil temperature on microbial growth has been further investigated by several researchers in recent years (Kirschbaum, 2000).

The main objectives of this work was to investigate the impact of heating irrigation water on plant growth and development of cucumber plant during winter season under greenhouse condition, as well as to study the influence of irrigation water temperature on the soil moisture content and the microbial activity of the soil.

MATERIAL AND METHODS:

Site description

Tulkarm area is recognized by its moderate climate, with average yearly precipitation varies between 530-630 mm, and relative humidity varies between (65-70%). Over the course of the year, the temperature typically varies from 8.3 °C to 31.7 °C and is rarely below 5 °C or above 33.3 °C.

Experimental design

A field experiment was conducted to study the impact of different irrigation water temperature levels on the cucumber crop cultivated inside the greenhouse of Palestine Technical University Kadoorie, Tulkarm, Palestine, in February 2018. Cucumber seedlings were cultivated in two rows: one covered with mulch and the other one without mulch. Irrigation water was applied manually at a rate of 1 L per plant at the beginning of the growing season and reached up to 3 L per plant during maturation stage. Compound chemical fertilizer was applied to the plants based on the nutrients requirement of cucumber plants as give in Table 1.

Treatments

Irrigation water temperature was heated and maintained at 30, 35 and 45 ºC using dolphin aquarium heaters. Irrigation water without heating (25 ºC) was used as control. Heated irrigation water was applied for both plants cultivated with and without mulch during irrigation regimes. Each plant row was contained four treatments replicated four times in each treatment. The experiment was designed using complete randomized design.

Observations

Soil samples were collected before cultivation to analyze the physio-chemical properties of the soil at initial condition. Soil texture was analyzed using hydrometer method. The pH and ECe were analyzed using saturation past method. Soil bulk density was measured using undisturbed soil auger method. Na and K was analyzed using flame-photometer method. The results of the soil analysis at initial condition are given in Table 2. Gravimetric soil moisture content and activity of soil microorganisms were estimated. For estimating the activity of soil microorganisms, 10 g of soil and 90 ml of distilled water were placed in a beaker to prepare the soil solution. The solution was placed on a magnetic stirrer device for 30 minutes and allowed to settle for 30 minutes. After that 100 µl of solution were taken and spread on a petri dish containing nutrient agar for bacterial proliferation and another cultivation was done on a petri dish contains PDA media for fungal proliferation. The petri dishes were incubated at 25 ºC for 24 to 48 hours for proper growth. Plant observation was monitored during the growing season including plant length, fruit number per plant and total yield. Chlorophyll content was measured using a SPAD meter.

Table (1). The nutrients requirement of cucumber crop under greenhouse in (g/du/day)

Growth stages	N	P_2O_5	K_2O
Transplanting – 14 days	100	100	100
15 – 35 days	200-250	100-150	250-300
36 – 115 days	350-400	200-250	350-500

Table (2). The physio-chemical properties of the soil at initial conditions

Parameters	Unit	Values
Sand	%	14
Silt	%	28
Clay	%	59
Texture		Clay
Bulk density	g/cm^3	1.23
FC	%	36
PWP	%	16
pH		8.3
ECe	dS/m	1.0
Ca^{2+}	mg/l	88.65
Mg^{+2}	mg/l	34
Na^{+}	mg/l	52.7
K^{+}	mg/l	8.15
Cl^{-}	mg/l	181.5
NO_3-N	mg/l	29.3
PO^{4-}	mg/l	11.15
HCO^{3-}	mg/l	61.7
CO^{3-}	mg/l	10.4

Data analysis

The statistical analysis of the data was carried out using Excel Stat Program (version 2021). Significant differences were computed using ANOVA after Tukey test at $P < 0.05$. Means with different letters are significantly different.

RESULTS:

Crop development

Results of this study showed that heating irrigation water temperature up to (35 °C) resulted in the highest plant length (173 cm) and (168 cm) in plants cultivated with and without mulch, respectively. At the end of the growing period, the irrigation water temperature (25 °C) produced the lowest plant length (134 cm) and (117 cm) in treatments with and without mulch, respectively (Figure 1).

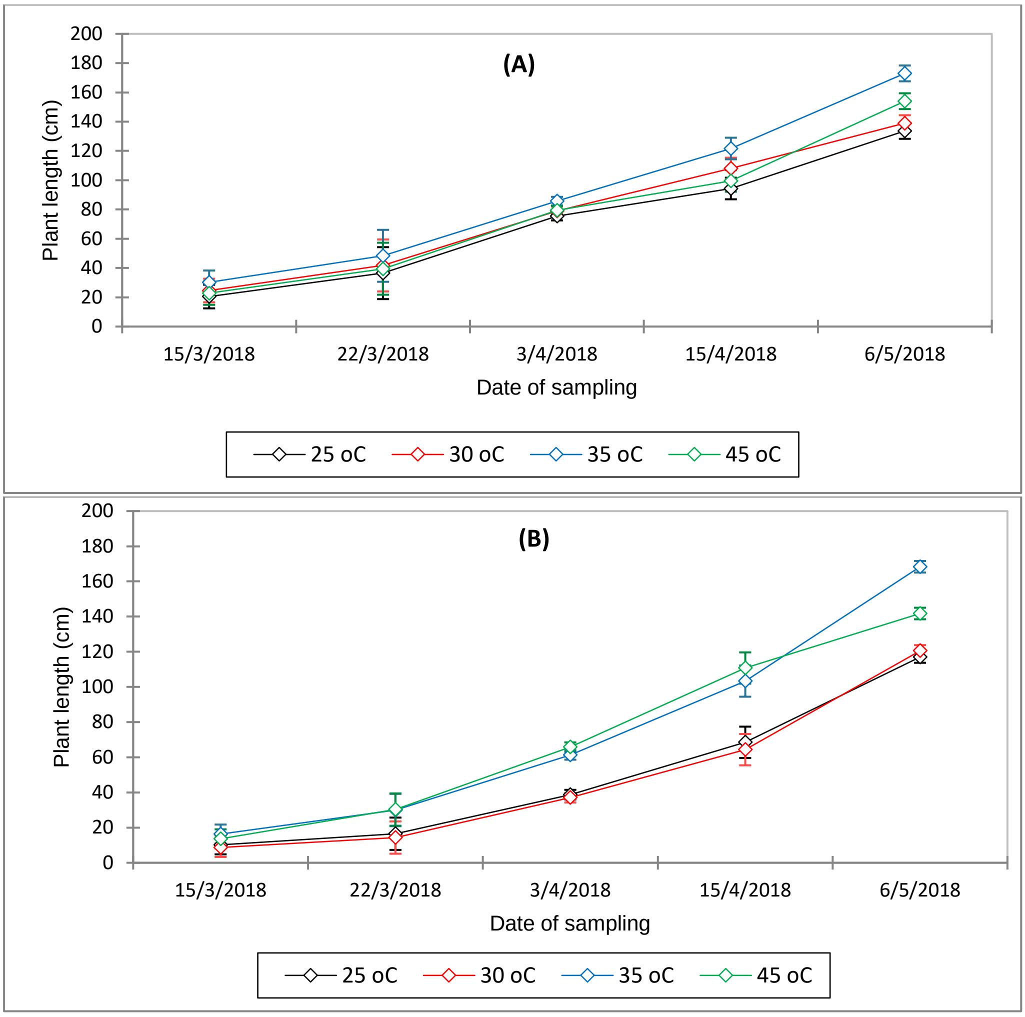

Figure (1). Plant length of cucumber crop cultivated with mulch (A) and without mulch (B) under different values of irrigation water temperature

Yield production

Average total yield was recorded for each treatment during the growing period. The results indicated that heating irrigation water supplied to the cucumber plants improved the vegetative growth and yield potential of cucumber crop. The impact of heating irrigation water temperature on the growth parameters of cucumber crop are given in Table 3. Findings of this study revealed that heating irrigation water temperature up to (35 °C) produced the highest yield (1498 g/plant) of cucumber plants compared with the other treatments mainly in mulch cover (Figure 2). The total yield production also showed a positive improvement under mulch treatment compared with that without mulch. Statistically, there were significant differences (P<0.05) between irrigation treatment heated at (35 °C) and the other treatments in plant grown with mulch, while there were no significant differences between treatments without mulch. The results also indicated that the fruit number of treatment heated at (35 °C) under mulch treatment produced the highest fruit number per plant (29.7 fruit/plant) compared to the other treatments (Figure 3). Statistically there were significant differences (P< 0.05) in fruit number between mulch and that without mulch under all irrigation water temperature treatments. Moreover, there were no significant differences between water temperatures at (35 °C) and (45 °C) treatments in case of mulch.

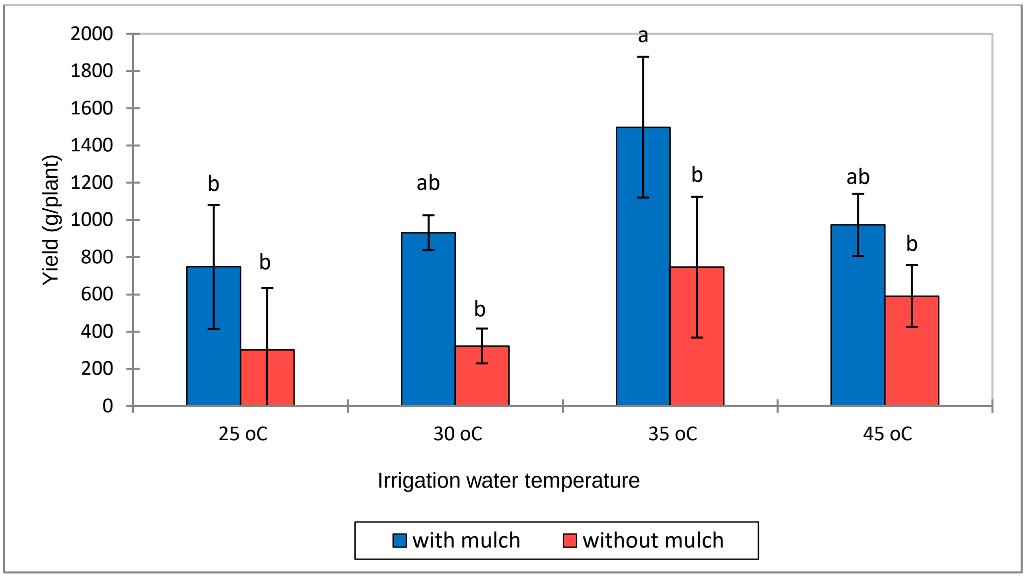

Figure (2). Yield of cucumber crop cultivated with and without mulch under different irrigation water temperature levels

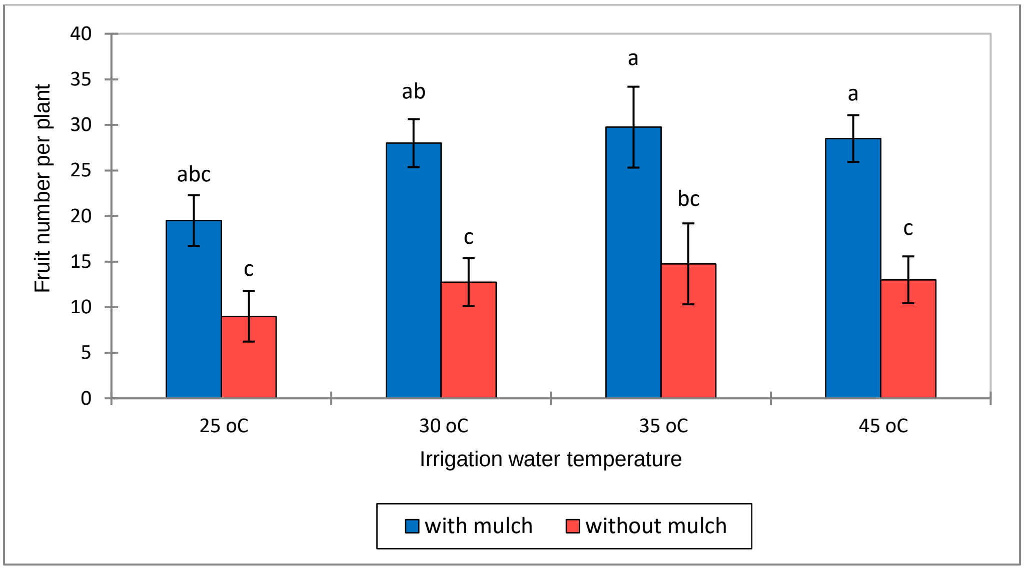

Figure (3). Fruit number of cucumber crop cultivated with and without mulch and under different irrigation water temperature levels

Table (3). Analysis of the difference between treatments at confidence interval of 95%

Treatments	Yield (g/plant)	Fruit number per plant	Chlorophyll content (SPAD)
25 °C with mulch	747.8[b]	19.5[abc]	114.1[a]
30 °C with mulch	930.9[ab]	28[ab]	114.1[a]
35 °C with mulch	1498.4[a]	29.7[a]	122.0[a]
45 °C with mulch	974.1[ab]	28.5[a]	121.9[a]
25 °C without mulch	302.7[b]	9[c]	113.8[b]
30 °C without mulch	323.1[b]	12.7[c]	117.9[ab]
35 °C without mulch	746.6[b]	14.7[bc]	119.1[ab]
45 °C without mulch	590.7[b]	13[c]	124.0[a]

Chlorophyll content

The findings of this study observed that heating irrigation water up to (45 °C) produced the highest chlorophyll content, followed by irrigation water temperature of (35 °C) mainly under that without mulch (Figure 4). Statistically, there were no significant differences in chlorophyll content between all treatment cultivated with mulch, while there were significant differences ($P < 0.05$) between water temperature of (35 °C) and (45 °C) in treatments without mulch.

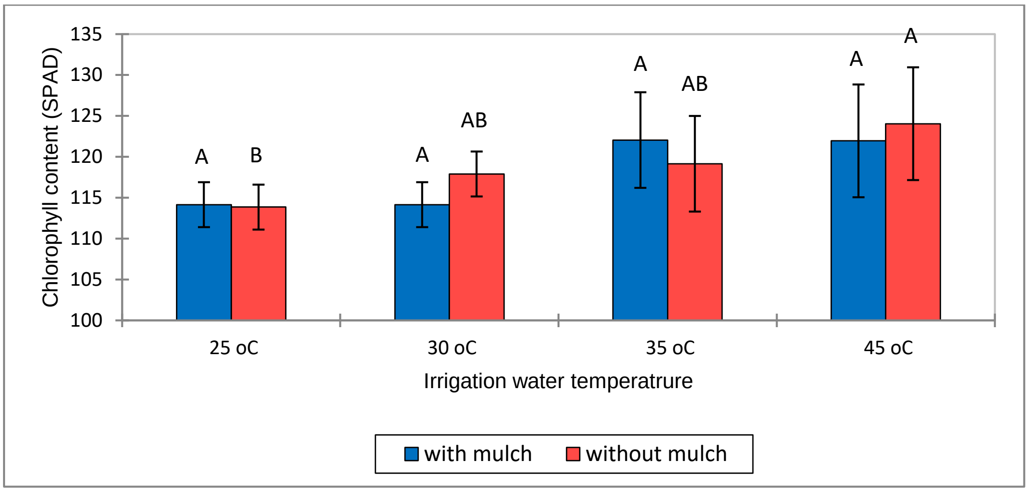

Figure (4). Chlorophyll content of cucumber crop cultivated with and without mulch under different irrigation water temperature levels

Soil microbial activity

It is reported that heating irrigation water enhanced the microbial activity of the soil mainly for the treatment irrigated with water temperature at (45 °C) without mulch (Figure 5). The statistical analysis showed that there were significant differences (P<0.05) in activity of soil microorganisms between all treatments without mulch. Also there were no significant differences in activity of soil microorganisms between irrigation water temperature of 30 °C and 45 °C in treatments with mulch.

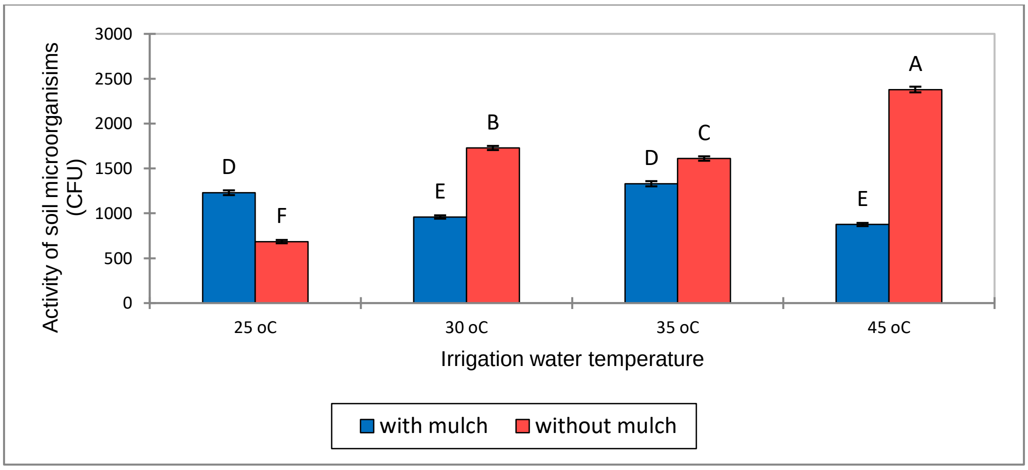

Figure (5). Activity of soil microorganisms under different irrigation water temperature levels

Soil moisture content

Soil moisture content was measured several times during the growing season. The finding of this study indicated that the soil moisture content of the treatments cultivated under mulch was higher than those cultivated without mulch (Figure 6). At the end of the growing season the higher soil moisture content (39%) was recorded in the treatment irrigated with water temperature at (35 °C) under mulch and reduced to (29%) without mulch at the same temperature.

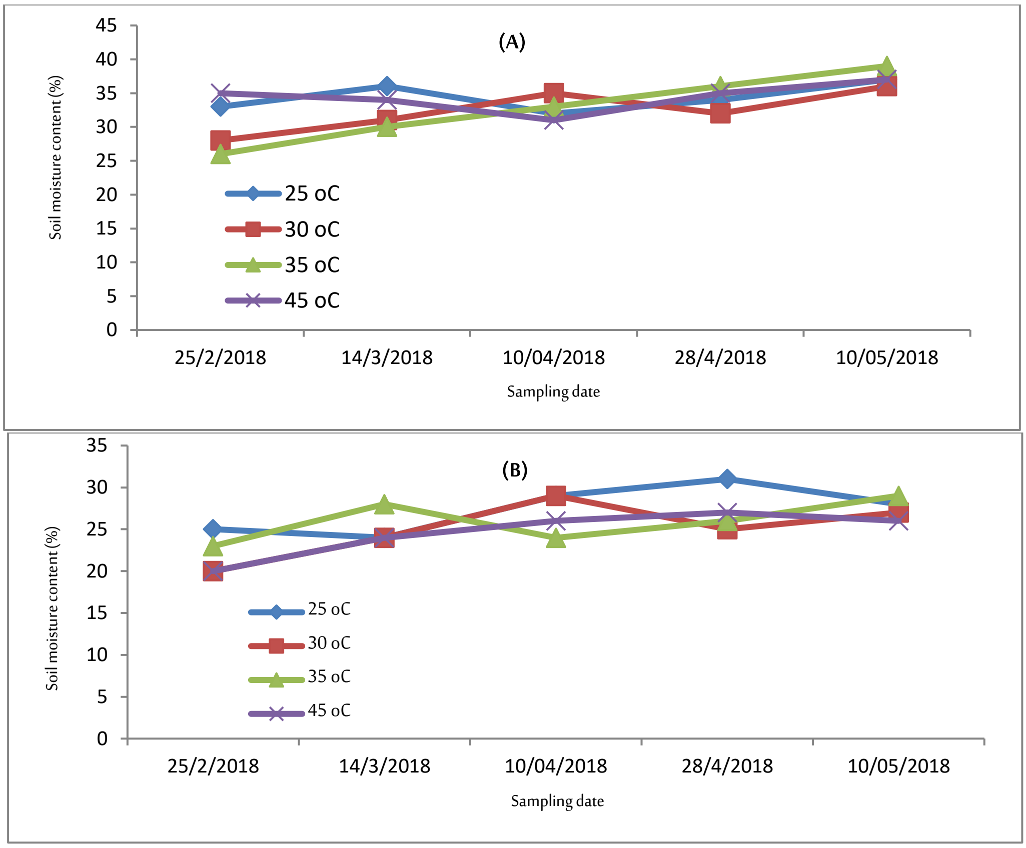

Figure (6). Soil moisture content for plants cultivated with mulch (A) and without mulch (B) under different values of irrigation water temperature

DISCUSSION:

The findings of this study revealed that all irrigation water temperature treatments cultivated with mulch produced higher plant length compared with those cultivated without mulch. This might be attributed to the positive impact of mulch in improving soil moisture content and improving soil temperature which enhanced the vegetative growth as well as increased the decomposition of organic matter and enhanced nutrient availability (Broadbent, 2015). Horton et al. (1996) found that mulch material reduced evaporation rate and increased soil moisture content. Broadbent (2015) reported that soil temperature between 21 – 38 ºC increased the mineralization of soil organic matter by stimulating microbial activities (Fang et al., 2005). Toselli et al. (1999) observed that the soil temperature has a great impact on plant growth and development by improving water absorption and nutrient uptake (Weih and Karlsson, 1999). Nxawe et al. (2009) found that the heated water of all hydroponic treatments had significantly higher length and number of leaves of spinach crop compared with the control (unheated water). Chung et al. (2006) observed that water temperature played an important role in developing plant growth. Onwuka and Mang (2018) reported that the soil moisture content and the availability of nutrient elements were highly influenced by soil temperature.

Moreover, it is observed that heating irrigation water temperature up to 35 ºC with mulch increased the yield significantly ($P < 0.05$) because of the enhancement of water and nutrient uptake by the roots. Results also showed that increasing irrigation water temperature up to (45 °C) under mulch reduced the yield production and the fruit numbers of cucumber crop as compared with the control treatment (unheated water). This is because mulch added extra temperature to the soil and reduced the activity of soil microorganisms, the decomposition rate of organic matter and the water and nutrient uptake by the plants.

Chlorophyll is considered an important pigment for photosynthetic process which influences plant growth and development to large extent. In this study chlorophyll pigment was measured using a SPAD meter. The control (25 ºC) treatment produced the lowest chlorophyll content for both mulch and without mulch treatments. Yun et al. (1998) and Kleinhenz et al. (2003) reported that the concentration of plant chlorophyll is mainly affected by environmental factors like temperature fluctuation. It is also found that low temperature may also influence the quality of chlorophyll pigment mainly under cold temperature (Lopez-Ayerra et al., 1998).

Temperature is an important factor that influencing the activity of soil microorganism. The findings of this study indicated that the microbial activity was inhibited at the irrigation water temperature of (45 ºC) with mulch. This may be attributed to the fact that mulch added extra temperature to the soil and affected the microbial activity in negative manner. Davidson and Janssens (2006) found that the soil micro-organisms influenced by soil temperatures between 10 - 35.6 ºC for their activities. Hussain and Maqsood (2011) reported that the soil temperature impacted the physical, chemical and biological reactions which affect nutrient availability and in turn affect plant nutrient uptake.

Concerning the soil moisture contents, the results of this study did not show a clear trend for the impact of irrigation water temperature treatments on soil moisture content for both plants cultivated with and without mulch. Horton et al. (1996) found that the plastic mulch inhibited the evaporation of soil water and hence improve soil moisture content. Consequently, this mulch reduced the temperature above ground surface (Shiners et al., 1994). Broadbent (2015) reported that when soil temperature was increased the water viscosity had reduced, thus allowing more water to transport through the soil profile.

CONCLUSION:

It is concluded that heating irrigation water temperature up to (35 ºC) played an important role in the growth and development of cucumber plants and improved the yield significantly compared to the control (unheated water) mainly under mulch cover. Heating irrigation water temperature up to (45 ºC) enhanced the soil microbial activity mainly without mulch cover. Furthermore, the activity of microorganisms was inhibited with mulch cover at the same temperature. Chlorophyll concentration and fruits number per plant were not affected significantly under different irrigation water temperature.

ACKNOWLEDGEMENTS:

The author would like to thank Prof. Mazen Salman from Palestine Technical University Kadoorie for his assistance in the statistical analysis.

REFERENCES:

Bite, A., & Lepsis, J. (2004). The results of extended duration testing of apple rootstocks in Latvia. Acta Horticulturae, (658), 115–118.

Broadbent, F.E. (2015). Soil organic matter. Sustainable options in land management, (2), 34–38.

Bubel, N. (2007). The new seed-starters. Handbook. Available online: http:www.green-seeds.com/seed_starters.pdf pp. 300.

Calatayud, A., Gorbe, E., Roca D., & Martinez, P.F. (2008). Effect of two nutrient solution temperatures on nitrate uptake, nitrate reductase activity, NH4+ concentration and chlorophyll a fluorescence in rose plants. Environmental and Experimental Botany, (64), 65–74.

Chung, I.M., Kim, J.J., Lim, J.D., Yu, C.Y., Kim S.H., & Hahn, S.J. (2006). Comparison of resveratrol, SOD activity, phenolic compounds and free amino acids in Rehmannia glutinosa under temperature and water stress. Environmental and Experimental Botany, (56) 44–53.

Clarkson, D.T., Jones L.H.P., & Purves, J.V. (1992). Absorption of nitrate and ammonium ions by Lolium perenne from flowing solution cultures at low root temperatures. Plant Cell and Environment, (15), 99–106.

Davidson, E.A., & Janssens, I.A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature, (440), 165–173.

Diaz-Perez, J.C., Gitaitis R., & Mandal, B. (2007). Effects of plastic mulches on root zone temperature and on the manifestation of tomato spotted wilt symptoms and yield of tomato. Scientia Horticlturae, (114), 90–95.

Dong, S., Scagel, C.F., Cheng, L., Fuchigami L.H., & Rygiewicz, P. (2001). Soil temperature and plant growth stage influence nitrogen uptake and amino acid concentration of apple during early spring growth. Tree Physiology, (21), 541–547.

El-Aidy, F., El-Zawely,A., Hassan, N., El-Sawy, M., 2007. Effect of plastic tunnel size on production of cucumber in delta of Egypt. Applied Ecology and Environmental Research, 5 (2), 11–24.

Fang, C., Smith, P., Moncrieff, J.B., & Smith, J.U. (2005). Similar response of labile and resistant soil organic matter pools to changes in temperature. Nature, (433), 57–59.

Frantz, J.M., Cometti, N.N., & Bugbee, B. (2004). Night temperature has a minimal effect on respiration and growth rapidly growing plants. Annales Botany, (94), 155–166.

Hatfield, J.L., Boote, K.J., Kimbal, B.A., Ziska, L.H., Izaurralde, R.C., Ort, D., Thomson, A.M., & Wolfe, D.W. (2011). Climate impacts on agriculture: implications for crop production. Agronomy Journal, (103), 351–370.

Horton, R., Bristow, R.I., Rluitenberg G.J., & Sauer, T.J. (1996). Crop residue effects on surface radiation and energy-balance review: Theoretical and Applied Climatology, (54), 27–37.

Hussain, A., & Maqsood, M.A. (2011). Root zone temperature influences nutrient accumulation and use in maize. Pakistan Journal of Botany, (43), 1551–1556.

Kirschbaum, M.U.F. (2000). Will changes in soil organic carbon act as a positive or negative feedback on global warming?. Biogeochemistry, 48: 21–51.

Kleinhenz, M.D., French, D.G., Gazula A., & Scheerens, J.C. (2003). Variety, shading and growth stage effects on pigment concentration in Lettuce grown under contrasting temperature regimes. HortTechnolology, (13), 677–683.

Kozai, T. (2006). Closed systems for high quality transplants using minimum Resources. Plant Tissue Culture Engineering, (6), 275–312.

Kurek, I., Chang, T., Bertain, S.M., Madrigal, A., Liu, L., Lassner M.W., & Zhu, G. (2007). Enhanced Thermostability of Arabidopsis Rubisco Activase Improves Photosynthesis and Growth Rates under Moderate Heat Stress. The Plant Cell, (19), 3230–3241.

Laubscher, C.P., & Ndakidemi, P.A. (2008). Rooting success using IBA auxin on endangered Leucadendron laxum (PROTEACEAE) in different rooting mediums. African Journal of Biotechnology, (7), 3437–3442.

Lee, S.H., Singh, A.P., Chung, G.C., Ahn, S.J., Noh, E.K., Steudle, E. (2004). Exposure of roots of cucumber (Cucumis sativus) to low temperature severely reduces root pressure, hydraulic conductivity and active transport of nutrients. Physiologia Plantarum, (120), 413–420.

Lopez-Ayerra, B., Murcia M.A., & Garcia-Carmona, F. (1998). Lipid peroxidation and chlorophyll levels in spinach during refrigerated storage and after industrial processing. Food Chemistry, (61) 113–118.

Markwell, J.P., Danko, S.J., Bauwe, H., Osterman J., and Gorz, H.J. (1986). A temperature-sensitive chlorophyll b-deficient mutant of sweet clover (Melilotus alba). Plant Physiology, (81), 329–334.

Moorby, J. and C.J. Graves, 1980. Root and air temperature effects on growth and yield of tomatoes and lettuce. Acta Horticulturae, (98) 29–44.

Nxawe, S., Ndakidemi P.A., & Laubscher, C.P. (2010). Possible effects of regulating hydroponic water temperature on plant growth, accumulation of nutrients and other metabolites. African Journal of Biotechnology, 9(54), 9128–9134.

Nxawe, S., Laubscher C.P., & Ndakidemi, P.A. (2009). Effect of regulated irrigation water temperature on hydroponics production of Spinach (Spinacia oleracea L.). African Journal of Agricultural Research, 4(12), 1442–1446.

Onwuka, B.M. (2016). Effects of soil temperature on Some Soil properties and plant growth. Scholarly Journal of Agricultural Science, 6(3), 89–93.

Onwuka, B.M., & Mang, B. (2018). Effects of Soil Temperature on Some Soil Properties and Plant Growth. Advances in Plants and Agricultural Research, 8(1), 37–41.

Paul, E.A., & Clark, F.E. (1996). Soil Microbiology and Biochemistry, 2nd edition, Academic Press, USA.

Peng, Y.Y., Dang, Q.L. (2003). Effects of soil temperature on biomass production and allocation in seedlings of four boreal tree species. Forest Ecology and Management, (180), 1–9.

Roh, M.S., & Hong, D. (2007). Inflorescence development and flowering of Ornithogalum thyrsoides hybrid as affected by temperature manipulation during bulb storage. Scientia Horticulturae, (113), 60–69.

Rosik-Dulewska, C.Z., & Grabda, M. (2002). Development and yield of vegetables cultivated on substrate heated by geothermal waters part 1: Bell pepper, slicing cucumber, tomato. Journal of Vegetable Crop Production, (8), 133–144.

Sakamoto, M., & Suzuki, T. (2015). Effect of root-zone temperature on growth and quality of hydroponically grown red leaf lettuce (Lactuca sativa L. cv. Red Wave). American Journal Plant Sciences, (6) 2350–2360.

Santarius, K.A. (2004). The protective effect of sugars on chloroplast membranes during temperature and water stress and its relationship to frost, desiccation and heat resistance. Planta, (113), 97–191.

Sethi, V.P. & Sharma, S.K. (2007). Greenhouse heating and cooling using aquifer water. Energy, (32), 1414–1421.

Shiners, K.J., Nelson W.S., & Wang, R. (1994). Effects of residue free band width on soil temperature and water content. Transactions of the ASAE, 37(1), 39–49.

Summerfield, R.J., Muehlbauer F.J., & Short, R.W. (1989). Controlled environments as an adjunct to field research on Lentils (Lens culinaris). IV. Cultivar responses to above- and below-average temperatures during vegetative growth. Experimental Agriculture, (25), 119–134.

Toselli, M., Flore, J.A., Marogoni, B., & Masia, A. (1999). Effects of root-zone temperature on nitrogen accumulation by non-breeding apple trees. Journal of Horticulture Science Biotechnology, (74), 118–124.

Weih, M., & Karlson, S. (1999). The nitrogen economy of mountain birch seedlings: implication for winter survival. Journal of Ecology, 87(2), 211–219.

Xu, Q., & Huang, B. (2006). Seasonal changes in root metabolic activity and nitrogen uptake for two cultivars of creeping bentgrass. Journal of Horticulture Sciences, (41), 822–826.

Yan, Q., Duan, Z., Mao, J., Xun, L., & Fei, D. (2013). Low root zone temperature limits nutrient effects on cucumber seedling growth and induces adversity physiological response. Journal of Integrative Agriculture, (12), 1450–1460.

Yun, J.G., Hayashi, T., Yazawa, S., Katoh, T., & Yasuda, Y. (1998). Abrupt and irreversible reduction of chlorophyll fluorescence associated with leaf spot in Saintpaulia (African violet). Scientia Horticulturae, (72), 157–169.