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The Effects of Water Temperature on Discharge and Uniformity Parameters of Emitters with Different Discharges, Types and Distances

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ABSTRACT

The research was conducted on emitter testing bench established in Irrigation laboratory, Suleyman Demirel University, Isparta, Turkey. In the study, discharge equations ($q= kH^x$), standard temperature discharge index (TDI, standard temperature is 20 °C) and uniformity parameters such as coefficient of manufacturing variation (CV), standard uniformity (Us), Christiansen uniformity (Cu) and emission uniformity (CUE) of in-line emitters with different discharges (D_1: 2.4 L h^{-1} and D_2: 4.0 L h^{-1}), types (T_B: Pressure compensating, T_T: Non-pressure compensating) and distances (A_1: 20 cm, A_2: 33 cm and A_3: 50 cm) under different water temperatures (20, 30, 40 and 50 °C) were determined. Effects of different pressures (from 80 to 200 kPa) on discharge of the emitters were also investigated. Discharges of non-pressure compensating emitters were increased by increasing pressure ($r \approx 0.99$). Although discharge was stable under high or recommended pressure in pressure compensating emitters, there was an increasing trend in emitter discharge under low pressure like non-pressure compensating emitters. Linear regressions were obtained between discharge and water temperature in non-pressure compensating and pressure compensating emitters ($r \approx 0.99$). Emitter discharge increased due to water temperature increase approximately 5 and 3% in non-pressure compensating and pressure compensating emitters, respectively. TDI values of non-pressure compensating emitters increased between 0.04 and 0.06 with increasing water temperature. In pressure compensating emitters, TDI values decreased 0.02 in $D_1A_1T_B$ emitter, did not change in $D_1A_2T_B$ emitter, and increased between 0.01 and 0.02 in other four emitters with increasing water temperature. Cv, Us, Cu and CUE values of the emitters under different water temperatures ranged between 0.023-0.044, 95.6-97.7%, 96.6-98.1% and 89.3-96.0%, respectively. Significant differences were obtained for each of these parameters in different water temperatures, emitter types and emitter distances. Generally, uniformity parameters improved in high water temperatures and the highest values of uniformity parameters were obtained from A_2 emitter distance in the tested emitters ($P<0.01$).

Keywords: Discharge; Emitter; Pressure; Uniformity; Water temperature

Farklı Debi, Tip ve Aralıklara Sahip Damlatıcıların Debilerine ve Eş Su Dağılımlarına Su Sıcaklığının Etkisi

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ÖZET

Bu araştırma Isparta Süleyman Demirel Üniversitesi Sulama laboratuarında kurulan damlatıcı test düzeneğinde yürütülmüştür. Çalışmada, farklı su sıcaklıkları (20, 30, 40 ve 50 °C) altında, farklı damlatıcı debilerine (D_1: 2.4 L h^{-1}, D_2: 4.0 L h^{-1}), damlatıcı tiplerine (T_B: Basınç düzenleyicili, T_T: Basınç düzenleyicisiz) ve damlatıcı aralıklarına (A_1: 20 cm, A_2: 33 cm, A_3: 50 cm) sahip 12 farklı içten geçik damlatıcının debi eşitlikleri ($q= kH^x$), standart sıcaklık debi indeksleri (TDI, standart sıcaklık 20 °C olarak alınmıştır) ve yapım faklılığı katsayısı (Cv), standart eş su dağılımı (Us), Christiansen eş su dağılım katsayısı (Cu) ve damlatıcı eş su dağılımı (CUE) gibi eş su dağılım parametreleri belirlenmiştir. Ayrıca, farklı işletme basınçlarının (80-200 kPa) damlatıcı debilerine olan etkileri incelenmiştir. Basınç düzenleyicisiz damlatıcı debileri artan işletme basıncı ile artmıştır (r≈ 0.99). Basınç düzenleyicili damlatıcı debileri ise yüksek veya önerilen basınçlarda sabit kalırken, düşük basınçlarda basınç düzenleyicisizlerde olduğu gibi artış göstermiştir. Hem basınç düzenleyicisiz hem de basınç düzenleyicili damlatıcılarda debi ve su sıcaklığı arasında doğrusal ilişki elde edilmiştir (r≈ 0.99). Su sıcaklığının artmasıyla debilerdeki artış basınç düzenleyicisiz damlatıcılarda yaklaşık % 5, basınç düzenleyicili damlatıcılarda ise yaklaşık % 3 olarak belirlenmiştir. Basınç düzenleyicisiz damlatıcıların TDI değerleri sıcaklık artışıyla 0.04 ile 0.06 arasında artmıştır. Basınç düzenleyicili damlatıcılarda ise TDI değerleri sıcaklık artışıyla, $D_1A_1T_B$'de 0.02 azalmış, $D_1A_2T_B$'de değişmemiş, ancak diğer dört damlatıcıda 0.01 ile 0.02 arasında artış göstermiştir. Farklı sıcaklıklar altında elde edilen Cv, Us, Cu ve CUE değerleri sırasıyla 0.023-0.044, % 95.6-97.7, % 96.6-98.1 ve % 89.3-96.0 arasında değişmiştir. Bu parametrelerin farklı su sıcaklıkları, damlatıcı tipleri ve damlatıcı aralıkları arasında istatistiksel olarak önemli farklar bulunmuştur. Test edilen damlatıcılarda genel olarak, eş su dağılım parametreleri yüksek su sıcaklıklarında yükselirken, en yüksek değerler A_2 damlatıcı aralığında elde edilmiştir ($P<0.01$).

Anahtar Kelimeler: Debi; Damlatıcı; Basınç; Eş su dağılımı; Su sıcaklığı

1. Introduction

Nowadays, global warming and rapid population growth have negative impact on water sources and increase water requirement for both urban and industrial areas in the world and Turkey. For this reason, irrigation water must be used more efficiently, especially, in countries like Turkey where approximately 73% of the total water consumption is used for agricultural irrigation. One of the most important reasons for excessive water use in agriculture is the using of surface irrigation systems with low efficiency (Yildirim 2012). Drip irrigation has an important potential with high irrigation efficiency, low energy consumption and water loss. Effective use of drip irrigation systems is depending on correct design of the system. Emitter is the most important elements of the system for efficient operation. High efficiency in drip irrigation systems depends on uniformity of emitter discharge. The most of the designs focus on pressure-emitter discharge relationships of the emitters because of variations in operating pressure in field condition due to land slope and head losses in pipes for the uniformity. However, emitter discharge and uniformity of drip irrigation systems are also influenced by other factors such as manufacturing variability, lateral diameter, emitter distance, clogging and water temperature changes (Ozekici & Sneed 1995; Rodriguez-Sinobas et al 1999; Clark et al 2005; Dutta 2008). While emitter clogging can be controlled by proper water filtration and system maintenance, manufacturing variability and temperature are often uncontrolled and variable parameters that can influence the discharge of individual emitters and the distribution uniformity of drip irrigation systems. Some water physical properties such as viscosity, density and emitter flow passage could be affected by temperature changes. Therefore, temperature changes cause changes in both friction loss and discharge (Peng et al 1986; Rodriguez-Sinobas et al 1999). In the field condition, drip irrigation laterals and emitters used in surface or near surface in the field may have full or partial exposure to the sun in warm and hot climates. Some researchers reported that drip lateral temperatures and soil temperatures during the day ranged from 26 to 42 °C and from 24 to 66 °C, respectively (Parchomchuk 1976; Nakayama & Bucks 1985; Abu-Gharbieh 1997). Under these conditions, buried drip irrigation laterals can act as a heat exchanger and absorb heat from the soil, thereby increasing the temperature of the water, resulting in a changed emitter discharge. Parchomchuk (1976) indicated that emitter discharge rates could increase about 53% when water temperature increased from 20 to 60 °C in microtube and spiral path emitters. Dogan & Kırnak (2010) concluded that when water temperature increased from 20 to 50 °C, flow rate changes due to irrigation water temperature increase varied from -7.5 to 16.1% and from -7.4 to 20.9% at pressure compensating emitters and non-pressure compensating emitters, respectively. Senyigit et al (2012) also claimed that the non-pressure compensating in-line emitter discharge increased with increasing temperature. The objective of this study was to evaluate the effects of different water temperatures and pressures on emitter discharge and the effects of different water temperatures on standard temperature discharge index and uniformity parameters.

2. Material and Methods

The study was conducted on emitter testing bench established in Irrigation Laboratory, Süleyman Demirel University, Isparta, Turkey in 2013 (Figure 1). Laterals were placed in the emitter testing bench without inclination. Graduated cylinders (1000 mL) with divisions every 10 mL located under each of the emitters were used to determine the emitter discharge. The pressure values were measured by manometers installed to the emitter testing bench and supply water was provided by a 216 L reservoir that had a small pump having 3.4 $m^3 h^{-1}$ discharge at 4.2 bar to pressurize the water. The water in the reservoir was heated by two resistances each of which has a capacity of 1500 Watts and the water temperature was tracked both by temperature sensor screen and by measurements from emitter output with a digital thermometer accurate to ±1 °C. Variation of temperature determined was less than 1 °C in each test. In the study, 12 different in-line emitters which are commonly used and produced by different manufacturers were used. Some physical properties of the emitters were shown in Table 1. In order to determine the effects of different water temperatures and pressures on discharge equations and the effects of different water temperatures on standard temperature discharge index (TDI), coefficient of manufacturing variation (CV), standard uniformity (Us), Christiansen uniformity (Cu) and emission uniformity (CUE) of different emitters, water temperatures of 20, 30, 40 and 50 °C and pressure values of 80, 90, 100, 110, 120, 130, 140, 150,160, 170, 180, 190 and 200 kPa were used.

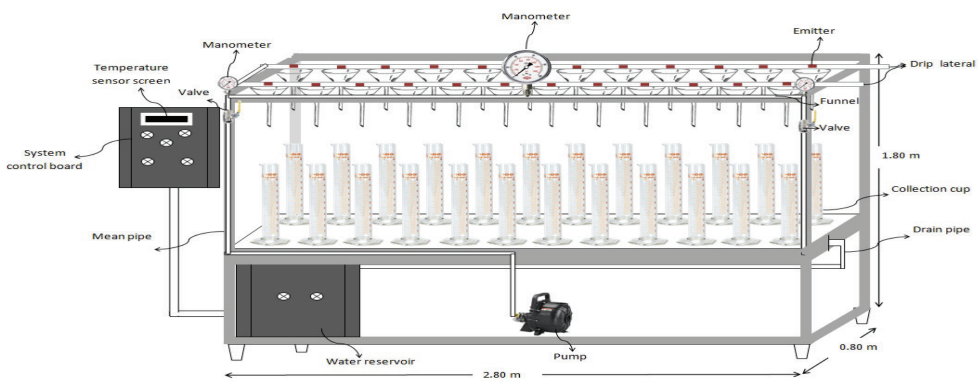

Figure 1- Emitter testing bench

Şekil 1- Damalatıcı test düzeneği

Table 1- Some physical properties of the tested emitters

Çizelge 1- Damlatıcıların kimi fiziksel özellikleri

Emitters	*Manufacturer recommended emitter discharge ($L\ h^{-1}$)*	*Lateral diameter (mm)*	*Emitter distance (cm)*	*Emitter number*
$D_1A_1T_T$	2.4	16	20	24
$D_1A_2T_T$	2.4	16	33	16
$D_1A_3T_T$	2.4	16	50	10
$D_1A_1T_B$	2.4	16	20	24
$D_1A_2T_B$	2.4	16	33	16
$D_1A_3T_B$	2.4	16	50	10
$D_2A_1T_T$	4	16	20	24
$D_2A_2T_T$	4	16	33	16
$D_2A_3T_T$	4	16	50	10
$D_2A_1T_B$	4	16	20	24
$D_2A_2T_B$	4	16	33	16
$D_2A_3T_B$	4	16	50	10

Each test was conducted by measuring the discharge of the emitters in testing bench under a constant temperature and different pressures. Before emitter discharge measurements, the system was operated for about 5 minutes to stabilize pressure. Emitter discharges were measured for 300 seconds, then collected water from each emitter was measured as volumetric and those values were converted to L h^{-1}. For the next test, the temperature was changed from sensor screen and waited least 30-40 minutes to equilibrate the temperature. After reaching to the desired temperature, the same measurements were repeated (Rodriguez-Sinobas et al 1999; Clark et al 2005).

Coefficients (k) and exponents (x) of emitter discharge and correlation coefficients were determined using regression test procedures (ASABE 2003) by emitter discharge equation (Equation 1).

$$q = kH^x \tag{1}$$

Where; q, emitter discharge (L h^{-1}); H, pressure (kPa); k, emitter coefficient; x, emitter exponent.

Standard temperature discharge index (TDI), standard variation (S), coefficient of manufacturing variation (CV), standard uniformity (Us), Christiansen uniformity (Cu) and emission uniformity (CUE) were calculated using Equation 2-7 (Christiansen 1942; Wu & Gitlin 1979; Bralts & Edwards 1986; ASABE 2003).

$$TDI = \frac{(qt^0)}{(qt_{20}^0)} \tag{2}$$

$$S = \left[\frac{\sum_{i=1}^{n} (q_i - q_{mean})^2}{n-1} \right]^{1/2} \tag{3}$$

$$CV = \frac{S}{q_{ort}} \tag{4}$$

$$U_s = 100(1 - CV) \tag{5}$$

$$Cu = 100(1 - \frac{\Delta q_o}{q_{mean}}) \tag{6}$$

$$CUE = 100\left[1 - \frac{1.27CV}{\sqrt{n}}\right]\frac{q_{min}}{q_{mean}} \tag{7}$$

Where; qt^0, emitter discharge at the test water temperature (L h^{-1}); qt^0_{20}, emitter discharge at the 20 ^oC (L h^{-1}); S, standard variation; q_i, emitter discharge (L h^{-1}); q_{mean}, average emitter discharge (L h^{-1}); n, total number of emitters; Δq_o, absolute deviation of the average (L h^{-1}); q_{min}, minimum discharge obtained from minimum pressure (L h^{-1}).

The effect of various pressures and water temperatures on uniformity parameters of emitters with different discharges, types and distances were analyzed by a factorial design analysis of variance and Tukey's test were used to determine the differences.

3. Results and Discussion

3.1. Discharge-pressure relationship

Discharges, emitter coefficients and exponents in discharge equation ($q= kH^x$) and R^2 values according to regression analyses from tested non-pressure compensating and pressure compensating emitters at different temperatures and pressures, were given in Table 2. Regression analyses of discharge and pressure relationships of all emitters were generally significant at 0.001 level. It was observed that the discharges of all non-pressure compensating emitters increased by increasing pressure (r≈ 0.99). The x values of the non-pressure compensating emitters were found to be close to 0.5 which showed that the flow was fully turbulent. Contrary to non-pressure compensating emitters, although discharge was stable under high or recommended pressure in pressure compensating emitters, there was an increasing trend in emitter discharge under low pressure like non-pressure compensating emitters. The x values were obtained near 0 as expected, this showed that the manufacturers emitters data to be compatible with the pressure compensating properties. This finding is confirmed by the findings of other previous studies (Rodriguez-Sinobas et al 1999; Clark et al 2005; Dogan & Kirnak 2010; Senyigit et al 2012). In addition, although discharge-pressure curves of the pressure compensating emitters remained constant at high or recommended pressures except $D_1A_1T_B$, increased in the low pressure as non-pressure compensating emitters. This finding is in agreement with the findings of Dutta (2008).

3.2. Water temperature-emitter discharge and standard temperature discharge index relationships

Linear regressions were obtained between emitter discharge and water temperature in non-pressure compensating and pressure compensating emitters (r≈ 0.99). Average emitter discharges strongly increased with increasing water temperature at non-

Table 2- Emitter coefficients, exponents and R^2 values of non-pressure compensating and pressure compensating emitters at different water temperatures

Çizelge 2- Basınç düzenleyicili ve basınç düzenleyicisiz damlatıcıların damlatıcı, katsayıları ve R^2 değerleri

	20 °C			*30 °C*			*40 °C*			*50 °C*		
Emitters	*x*	*k*	*R^2*	*x*	*k*	*R^2*	*x*	*k*	*R^2*	*x*	*k*	*R^2*
$D_1A_1T_T$	0.52	0.21	0.996***	0.52	0.21	0.998***	0.52	0.22	0.998***	0.50	0.24	0.997***
$D_1A_2T_T$	0.51	0.22	0.996***	0.50	0.24	0.992***	0.49	0.24	0.995***	0.46	0.29	0.998***
$D_1A_3T_T$	0.52	0.24	0.993***	0.50	0.26	0.998***	0.52	0.24	0.998***	0.51	0.26	0.998***
$D_2A_1T_T$	0.52	0.35	0.992***	0.51	0.38	0.998***	0.52	0.37	0.998***	0.51	0.40	0.998***
$D_2A_2T_T$	0.50	0.44	0.998***	0.50	0.45	0.996***	0.51	0.44	0.996***	0.47	0.53	0.999***
$D_2A_3T_T$	0.52	0.45	0.998***	0.52	0.45	0.999***	0.49	0.52	0.999***	0.48	0.54	0.998***
$D_1A_1T_B$	0.02	2.66	0.575***	0.01	2.27	0.185*	0.03	2.04	0.504***	0.05	1.85	0.860***
$D_1A_2T_B$	0.08	1.64	0.740***	0.10	1.47	0.932***	0.10	1.48	0.925***	0.13	1.31	0.952***
$D_1A_3T_B$	0.22	0.82	0.992***	0.24	0.76	0.998***	0.22	0.81	0.990***	0.25	0.73	0.982***
$D_2A_1T_B$	0.09	2.58	0.756***	0.12	2.23	0.805***	0.15	1.97	0.914***	0.13	2.19	0.857***
$D_2A_2T_B$	0.13	2.02	0.954***	0.14	1.93	0.939***	0.15	1.79	0.981***	0.16	1.75	0.990***
$D_2A_3T_B$	0.10	2.37	0.866***	0.13	2.13	0.887***	0.14	1.99	0.944***	0.13	2.12	0.934***

*, significant at 0.05 level; ***, significant at 0.001 level

pressure compensating emitters and slightly increased with increasing water temperature at pressure compensating emitters. The rate of emitter discharge increase due to increased water temperature (from 20 to 50 °C) was approximately 5 and 3% at non-pressure compensating and pressure compensating emitters, respectively (Figure 2). Similarly, Dogan & Kirnak (2010) claimed that water temperature generally tend to increase discharge of non-pressure compensating and pressure compensating emitters. Some other researchers also explained the relationship between water temperature and discharge with linear regression similar to our study (Parchomchuk 1976; Dogan & Kirnak 2010).

Standard temperature discharge index (TDI) values were obtained with emitter discharge measured at different water temperatures and then regression analyses were performed (Figure 3). TDI values except $D_1A_2T_B$ showed linear relationships among different water temperatures, this result is also in agreement with previous findings (Zur & Tal 1981; Dogan & Kirnak 2010). TDI values of non-pressure compensating emitters increased between 0.04 and 0.06 with increasing water temperature. In pressure compensating emitters, TDI values decreased in $D_1A_1T_B$ emitter as 0.02 and constant in $D_1A_2T_B$ emitter, but increased between 0.01 and 0.02 in other four emitters with increasing water temperature. The results are consistent with some previous findings by Rodriguez-Sinobas et al (1999) and Dogan & Kirnak (2010). As a result, water temperature is an important factor to affect changing of TDI values depending on the emitter type. Clark et al (2005) reported similar results which indicated that highly undesirable discharge distributions in drip irrigation systems could be provided with emitter exposed to sunlight or very warm water conditions.

CV values were obtained as lower than 0.05 for all emitters and varied from 0.023-0.044 and 0.031-0.043 at non-pressure compensating and pressure compensating emitters, respectively (Table 3). While the lowest CV values in non-pressure compensating

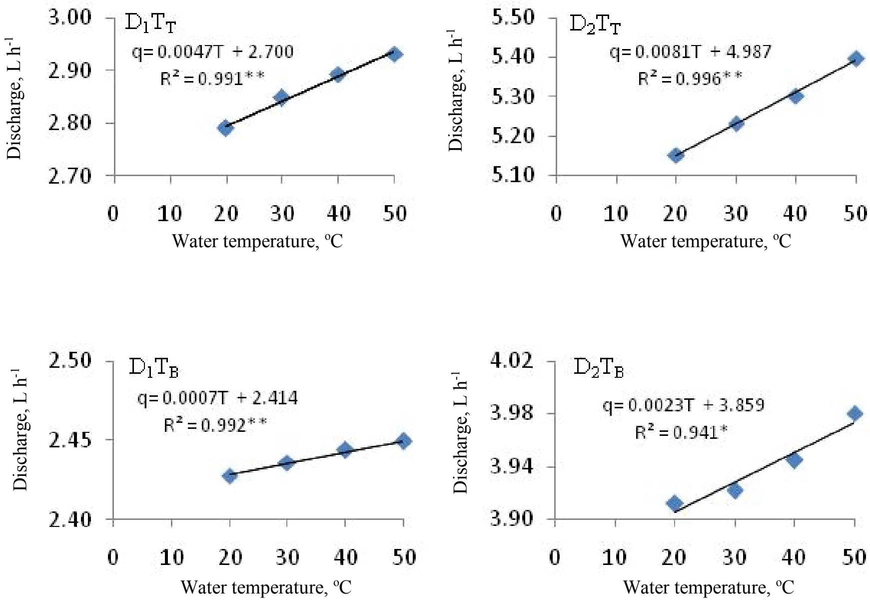

Figure 2- Water temperature-discharge relationships of the non-pressure compensating and pressure compensating emitters with different discharges

Şekil 2- Farklı debilere sahip basınç düzenleyicili ve basınç düzenleyicisiz damlatıcılarda su sıcaklığı-debi ilişkisi

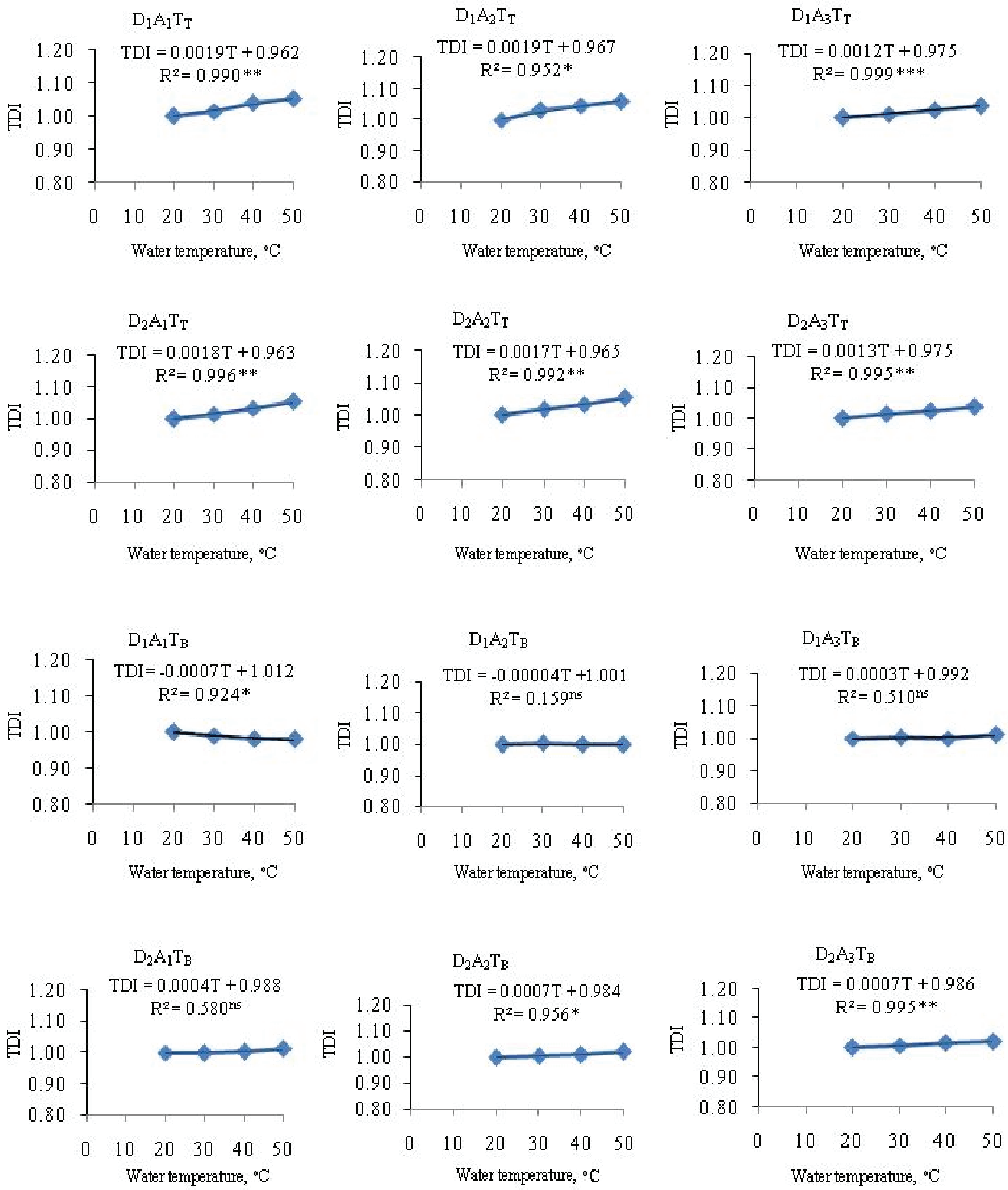

Figure 3- Water temperature-standard temperature discharge index (TDI) relationships of the emitters

Şekil 3- Damlatıcıların su sıcaklığı-standart sıcaklık debi indeks ilişkileri emitters with D_1 were obtained at 40 and 50 °C water temperatures, CV values were not affected from changes in water temperature for other emitters (P<0.01). However, CV value of non-pressure compensating emitter was lower than pressure compensating emitter's at 50 °C in both D_1 and D_2. Our results except decreased CV values in high water temperatures in non-pressure compensating emitters with D_1 are similar with Clark et al (2005) and Dogan & Kirnak (2010) who indicated that there was no relationship between CV and water temperature. In addition, the lowest CV values between the means of emitter distances in various water temperatures were obtained from A_2 for emitters with both D_1 and D_2 (P<0.01). Mean Us values of all emitters were obtained higher than 96% which was described as "excellent" class according to ASAE (2002). The Us values changed between 95.6 and 97.4% at non-pressure compensating emitters, while those values changed between 95.7 and 96.9% at pressure compensating emitters (Table 3). The effects of water temperatures on Us were found to be similar to those found for CV since Us is the function of CV.

Table 3- Cv and Us values of the emitters with different discharges, types and distances under different water temperatures

Çizelge 3- Farklı debi, tip ve aralıklara sahip damlatıcıların farklı su sıcaklıklarında Cv ve Us değerleri

CV						
Emitters		*Water temperature (°C)*				*Mean*
		20	*30*	*40*	*50*	
D_1	T_T	0.036 ABa	0.038 Bb	0.033 Aa	0.034 Aa	0.036
	T_B	0.035 Ab	0.035 Aa	0.035 Aa	0.037 Ab	0.035
	Mean	0.036	0.037	0.034	0.036	
D_2	T_T	0.033 Aa	0.032 Aa	0.032 Aa	0.030 Aa	0.032
	T_B	0.035 Aa	0.035 Aa	0.033 Aa	0.036 Ab	0.035
	Mean	0.034	0.034	0.033	0.034	
D_1	A_1	0.037	0.037	0.033	0.036	0.036 b
	A_2	0.029	0.029	0.029	0.028	0.029 a
	A_3	0.041	0.044	0.041	0.043	0.042 c
	Mean	0.036	0.037	0.034	0.036	
D_2	A_1	0.038	0.038	0.035	0.038	0.037 b
	A_2	0.027	0.027	0.028	0.027	0.027 a
	A_3	0.037	0.036	0.033	0.035	0.035 b
	Mean	0.034	0.034	0.032	0.034	

Us						
Emitters		*Water temperature (°C)*				*Mean*
		20	*30*	*40*	*50*	
D_{1w}	T_T	96.4 Aba*	96.2 Bb	96.7 Aa	96.6 Aa	96.4
	T_B	96.5 Aa	96.5 Aa	96.6 Aa	96.3 Ab	96.5
	Mean	96.4	96.3	96.6	96.4	
D_2	T_T	96.7 Aa	96.8 Aa	96.8 Aa	97.0 Aa	96.8
	T_B	96.5 Aa	96.5 Aa	96.7 Aa	96.4 Ab	96.5
	Mean	96.6	96.6	96.8	96.6	
D_1	A_1	96.3	96.3	96.7	96.4	96.4 b
	A_2	97.1	97.1	97.1	97.2	97.1 a
	A_3	95.9	95.6	95.9	95.7	95.8 c
	Mean	96.4	96.3	96.6	96.4	
D_2	A_1	96.2	96.2	96.5	96.2	96.3 b
	A_2	97.3	97.3	97.2	97.3	97.3 a
	A_3	96.3	96.4	96.7	96.5	96.5 b
	Mean	96.6	96.6	96.8	96.6	

*, capital Latin letters show differences between the columns, small Latin letters show differences between the rows

Generally, Cu values ranged from 97.0 to 97.5% in all emitters under different water temperatures (Table 4). While Cu values did not provide the condition as Cu≥ 98% suggested by Perold (1977), Cu≥ 95% condition recommended by Wu & Gitlin (1979) was provided in almost all emitters. While there was no statistical difference between Cu values at different water temperatures in both non-pressure compensating and pressure compensating emitters, Cu value of non-pressure compensating emitter was higher than pressure compensating emitter's at only 50 °C water temperature for both D_1 and D_2 (P<0.01). Furthermore, the highest Cu values between the means of emitter distances at various water temperatures were obtained in A_2 for the emitters with both D_1 and D_2 (P<0.01). CUE values classified as "good- excellent" class according to ASAE (2002) stayed between 87 and 94% (Table 4). However, CUE values were "excellent" class in A_2 emitter distance of both non-pressure compensating and pressure compensating emitters. The highest CUE values at non-pressure compensating emitters with D_1 were obtained from 40 and 50 °C water temperatures (P<0.01), while those values were not affected by water temperature at pressure compensating emitters. In addition, means CUE

Table 4- Cu and CUE values of the emitters with different discharges, types and distances under different water temperature

Çizelge 4- Farklı debi, tip ve aralıklara sahip damlatıcılıarın Cu ve CUE değerleri

		Cu				
Emitters		*Water temperature (°C)*				*Mean*
		20	*30*	*40*	*50*	
D_1	T_T	97.2 Aa*	97.1 Aa	97.4 Aa	97.4 Aa	97.3
	T_B	97.3 Aa	97.2 Aa	97.2 Aa	97.0 Ab	97.2
	Mean	97.2	97.2	97.3	97.2	
D_2	T_T	97.4 Aa	97.4 Aa	97.5 Aa	97.7 Aa	97.5
	T_B	97.5 Aa	97.4 Aa	97.5 Aa	97.3 Ab	97.4
	Mean	97.5	97.4	97.5	97.5	
D_1	A_1	97.1	97.1	97.5	97.2	97.2 b
	A_2	97.7	97.8	97.7	97.8	97.7 a
	A_3	96.8	96.6	96.7	96.6	96.7 c
	Mean	97.2	97.2	97.3	97.2	
D_2	A_1	97.0	97.0	97.2	97.1	97.1 c
	A_2	97.9	97.7	97.8	98.0	97.9 a
	A_3	97.3	97.4	97.5	97.4	97.4 b
	Mean	97.5	97.4	97.5	97.5	
		CUE				
Emitters		*Water temperature (°C)*				*Mean*
		20	*30*	*40*	*50*	
D_1	T_T	92.1Bb	91.2Cb	93.5Ab	92.8ABa	92.4
	T_B	93.3Ba	93.3Ba	94.2Aa	93.3Ba	93.5
	Mean	92.7	92.3	93.9	93.1	
D_2	T_T	93.6	95.3	93.8	94.1	93.7a
	T_B	92.6	92.9	93.3	92.4	92.8b
	Mean	93.1	93.2	93.5	93.3	
D_1	A_1	91.5	91.5	93.2	92.4	92.2b
	A_2	94.4	94.3	94.7	95.0	94.6a
	A_3	92.1	91.0	93.4	92.2	92.2b
	Mean	92.7	92.3	93.9	93.1	
D_2	A_1	91.3	91.0	91.7	91.8	91.5c
	A_2	95.5	95.5	95.1	94.9	95.3a
	A_3	92.5	93.1	93.9	93.0	93.1b
	Mean	93.1	93.2	93.5	93.3	

*, capital Latin letters show differences between the columns, small Latin letters show differences between the rows

value of non-pressure compensating emitters (93.7%) was higher than pressure compensating emitter's (92.8%) in D_2 according to CUE values under different water temperatures (P<0.01).

4. Conclusions

In the present study, the effects of different water temperatures and pressures on emitter discharges and the effects of different water temperatures on standard temperature discharge index and uniformity parameters were tested using 12 different in-line emitters with different discharges, types and distances. Study results showed that emitter discharges of non-pressure compensating emitters were increased linearly by increasing pressure. Although discharge-pressure curves were a constant under high or recommended pressure in compensating emitters, the curves rose like non-pressure compensating emitters under low operating pressure.

Mean emitter discharges of all emitters in the experiment were increased with water temperature and linear relationships were observed between discharge and water temperature. In addition, TDI values except $D_1A_2T_B$ showed linear relationships among different water temperatures**.** It can be concluded that water temperature had an important effect on changing of TDI values depending on the emitter type.

Significant differences were obtained between the values of uniformity parameters of emitters with different discharges, types and distances under different water temperatures (P<0.01). While uniformity parameters generally improved in high water temperature (40 and 50 ^{o}C) in non-pressure compensating emitters, the data indicated that no significant effect of water temperature on uniformity parameters in pressure compensating emitters. In addition, the highest uniformity parameters values were obtained from A_2 emitter distance in the tested emitters. However, in general, there was no significant difference between the non-pressure compensating and pressure compensating emitters with regard to uniformity parameters except Cu.

While the most of manufacturers provide x and k coefficients values of the emitter discharge equation at standard temperature (20 ^{o}C), the effects of different temperature on emitter discharge were not considered. According to our results, providing the response data of different water temperatures on emitter discharges by manufacturers to designers will be useful strategy to organize more accurate project and efficient drip irrigation system. In addition, drip irrigation system users should also measure water temperature and make associated correction during operation in the field for high performance.

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