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Determination of Hydraulic Performance of Trickle Irrigation Emitters used in Irrigation Systems in the Harran Plain

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Abstract: Trickle irrigation systems' efficiency depends on system uniformity, which is determined by water discharge uniformity from emitters. It is impossible to produce 2 identical emitters due to manufacturing variations. The manufacturer's coefficient of variance is used as a measure of discharge variations of emitters. In this study, manufacturers' reported discharge rates and coefficients of manufacturing variation (CVm) values were compared with test results for various types of in-line emitters manufactured by 4 different companies in Turkey. A total of 9 drip irrigation lines, comprising 7 non-compensating and 2 compensating emitters, were tested at 50, 100, 150, 200 and 250 kPa pressures. Non-compensating emitter types were not tested at 250 kPa. Compensating emitter exponents ranged from 0.02 to 0.05 while non-compensating emitters' values varied between 0.60 and 0.85. Test results showed that only 1 of the 7 non-compensating emitters and both compensating emitters had flow rates within ± 10% of manufacturers' reported values. The t-test between manufacturers' reported and measured mean flow rates at manufacturers' reported nominal operating heads showed that there was no significant statistical difference at the $\alpha < 0.05$ level. According to ASAE standards, the measured coefficients of manufacturing variation values for non-compensating emitters were not acceptable, although compensating emitters were in the excellent class.

Key Words: Drip irrigation, in-line emitters, manufacturers' coefficient of variance, emitter exponent.

Harran Ovası Sulamasında Kullanılan Damlatıcıların Hidrolik Performansının Belirlenmesi

Özet: Damla sulama sisteminin etkinliği damlatıcılardan çıkan debinin eşdeşliğine bağlıdır. Her yönüyle aynı iki damlatıcının üretimi imkansızdır. Yapım farklılık katsayısı, damlatıcılardaki debi değişiminin belirlenmesinde kullanılır. Çalışmada; içten geçmeli damlatıcılardaki yapım farklılıkları ile değişik basınçlardaki debiler, üretici firma ve test sonuçları ile kıyaslanmıştır. Üretici firmalardan elde edilen değişik türden 9 damlatıcının beş ayrı işletme basıncındaki debileri ölçülmüştür. Basınç düzenleyicili damlatıcılar 50, 100, 150, 200 ve 250 kPa altında buna karşılık basınç düzenleyicisiz damlatıcılar 250 kPa işletme basıncı haricinde aynı şekilde test edilmiştir. Basınç düzenleyicisiz damlatıcılarda, damlatıcı katsayısı 0.60 ile 0.85 arasında değişirken bu değer basınç düzenleyicili damlatıcılarda 0.02 ile 0.05 arasında olmuştur. Üretici firmalar tarafından önerilen işletme basıncında test edilen yedi basınç düzenleyicisiz damlatıcılardan yalnız bir tanesi ± %10 sınırı içinde kalmıştır. Buna karşın test edilen her iki basınç düzenleyicili damlatıcıda debi değişimi bu sınır içinde kalmıştır. Üretici firmalar tarafından önerilen işletme basıncındaki ortalama damlatıcı debileri ile test sonucunda ölçülen ortalama damlatıcı debileri arasında yapılan t-istatistiği ($\alpha < 0.05$), önemsiz bir ilişkinin olduğunu göstermiştir. ASAE standartlarına göre, yapım farklılık katsayısı, basınç düzenleyicisiz damlatıcılarda kabul edilemez sınırlar içinde iken basınç düzenleyicili damlatıcılarda mükemmel sınır içinde kalmıştır.

Anahtar Sözcükler: Damla sulama, içten geçmeli damlatıcılar, yapım farklılık katsayısı, damlatıcı katsayısı.

Introduction

Drip irrigation systems can apply frequent and small amounts of irrigation water at many points of a field surface/subsurface near the plants (Decroix and Malaval, 1985; Youngs et al., 1999). With drip irrigation, plant water and fertilizer requirements can also be applied to the plant root zone with minimum losses, maintaining steady moisture in the soil profile. In addition, drip

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irrigation systems have the advantage of fitting difficult topography (Wei et al., 2003).

The purpose of irrigation is to supply water to plants as needed through replenishment of root-zone moisture storage when natural rainfall is inadequate or poorly distributed. However, it is nearly impossible, and economically unfeasible, for an irrigation system to apply the same amount of water to all plants within a field. Therefore, in most cases, irrigation nonuniformity is the major source of reduced crop yields (Wu, 1987; Bhatnagar and Srivastava, 2003).

The drip irrigation system offers the highest irrigation uniformity compared with other irrigation systems. A successful uniform drip irrigation system application depends on the physical and hydraulic characteristics of the drip tubing (Al-Amound, 1995). Drip irrigation system efficiency depends on application uniformity. In surface drip irrigation systems, uniformity can be evaluated by direct measurements of emitter flow rates. According to Mizyed and Kruse (1989), the main factors affecting drip irrigation system uniformity are: (1) manufacturing variations in emitters and pressure regulators, (2) pressure variations caused by elevation changes, (3) friction head losses throughout the pipe network, (4) emitter sensitivity to pressure and irrigation water temperature changes, and (5) emitter clogging. Similarly, Capra and Scicolone (1998) indicated that the major sources of emitter flow rate variations are emitter design, the material used to manufacture the drip tubing, and precision.

Aridity and shortage of fresh water are the 2 main obstacles to agricultural development. Irrigation is an essential component of intensive crop production in the Harran plain in Turkey, simply due to erratic rainfall. More than 90% of the current irrigation practices in the Harran plain are surface irrigation. However, in recent years in the irrigation of vegetable and horticultural crops, drip irrigation technology has been slowly accepted by the farmers in the area. There is a shortage of studies on the evaluation of the hydraulic characteristics of drip irrigation tubing sold in the region. Therefore, in this study, manufacturers' reported discharge rates and the coefficients of manufacturing variation values of popular drip tubes widely used in the region were compared with measured values.

Manufacturers' variation

Small differences between what appears to be identical emitters may result in significant discharge variations. The manufacturer's coefficient of emitter variation is a measure of the variability of discharge of a random sample of a given make, model and size of emitter, as produced by the manufacturer and before any field operation or aging has taken place (ASAE, 1996). The manufacturer's coefficient of emitter variation (CV_m) is defined as

$$CV_m = s / q_a \tag{1}$$

where

CV_m = the manufacturer's coefficient of emitter variation,

s = standard deviation of emitter discharge rates at a reference pressure head (l h^{-1}) and

q_a = average discharge rate of emitters at that reference pressure head (l h^{-1}).

The manufacturer's variation is mainly caused by pressure and heat instability during emitter production. In addition, a high CV_m could occur due to a heterogeneous mixture of the materials used in the production of emitters. Typical values for CV_m range from 2 to 15%, although higher values are possible (Pitchford, 1980; Boswell, 1985). Classifications of CV_m values according to ASAE standards are shown in Table 1. In this study the method described above (Equation 1) was used.

Table 1. ASAE recommended classification of manufacturer's coefficient of variation (CV_m).

CV_m (%)	Classification
<5	excellent
5-7	average
7-11	marginal
11-15	poor
>15	unacceptable

Emitter exponents

The emitter is the most important part of drip irrigation tubing. An emitter with a high degree of pressure compensation (x = 0) is technically possible, although the ideal emitter has not yet been invented. Emitter flow rates may fluctuate as pressure along the lateral line varies due to friction, elevation, and/or accidental restrictions, resulting in a non-uniform water application (Braud and Soon, 1980; Bralts et al., 1981). Emitter discharge rate is a function of operating pressure as described in the power law

$$q = KH^x \tag{2}$$

where

K = emitter constant, including factors to make units consistent,

H = operating pressure (kPa) and

x = emitter exponent.

The sensitivity to H of an emitter discharge depends mainly on the values of x, which determines how sensitive the discharge is to pressure. The value of x typically falls between 0.1 and 1.0, mainly depending on the make and design of the emitter, i.e. hydraulic characteristics. For a fully laminar flow regime, emitters must be very sensitive to pressure head changes and the value of x must be 1.0. This means that a pressure variation of 20% may result in ± 20% emitter flow rate variation. Most non-compensating emitters are always fully turbulent with an x level of about 0.5, indicating that a pressure variation of 20% will result in a flow variation of approximately 10%. On the other hand, for compensating emitters, pressure variations cause little discharge variation. Compensating emitters have an x level ranging from 0.1 to 0.4. An ideal pressure compensating emitter would have an x level equal to 0 (Braud and Soon, 1980; Solomon and Bezdek 1980; Boswell, 1985). Equation 2 was utilized to calculate the x values in this study.

Materials and Methods

The ASAE test standards procedure was followed to determine the effects of different drip emitter design CVm and consistency of flow rates. Nine different drip tubing types (7 non-compensating and 2 compensating) obtained from 4 different manufacturers were used in the laboratory tests to determine CV_m, x, and k values at 5 different pressures (50, 100, 150, 200 and 250 kPa). For nominal flow rate and manufacturers' coefficients the non-compensating emitters were tested at a pressure of 100 kPa while the compensating emitters were tested at 250 kPa pressure, as suggested by the manufacturers (Table 2). Compensating emitter types were tested at 50, 100, 150, 200 and 250 kPa to determine CV_m, x, and k values using Equations 1 and 2. Non-compensating emitters were tested at the same pressures, except for 250 kPa (Eq. 2).

A 1-inch main pipeline with zero slope was used and 2 pressure gauges were located immediately before and after the 150 mesh screen filter. The water source for the tests was local city water with a pH and electrical conductivity of 7.2 and 0.53 mmhos cm^{-1}, respectively.

Manufacturer reported nominal emitter flow rates for the non-compensating emitters varied from 1.1 to 4.0 l h^{-1} based on emitter types, while compensating emitters had 3.8 l h^{-1} discharge rates (Table 2). All drip lines had a 16.0 mm outer diameter, except for A3, which had a 20.0 mm diameter, while inner diameters ranged from 13.8 mm to 18.2 mm. The emitter spacing varied from 20 cm to 90 cm and suggested operating pressures of 100 and 250 kPa for non-compensating and compensating emitters, respectively.

The lateral length used in all test runs was kept small (<10 m) in order to minimize friction losses and to obtain a desired constant pressure. Five laterals consisting of 10 emitters (a total of 50 emitters to meet ASAE, 1996 standards) were tested simultaneously. Measurements were taken after the system was run for 1 h in order to obtain a constant pressure head. Emitter discharge rates were measured with small containers located under each emitter. Water in the containers was afterwards weighed using a 0.1% accurate balance. Water was dripped into the container for exactly 1 h. The water temperature during the test was about 23 °C.

Results and Discussion

The t-test between manufacturers' reported mean flow rates and measured mean flow rates at manufacturers' reported nominal operating pressures showed that there was no significant statistical difference at the $\alpha < 0.05$ level (Table 2). The non-compensating emitters' discharge rates increased when the operational pressure head increased, as was expected. On the other hand, the compensating emitters' discharge was almost constant (a variation of ± 0.2 lh-1) under different pressures, again as was expected (Table 3).

The calculated x and k values of all emitter types ranged from 0.022 to 0.850 and from 0.2236 to 3.5684, respectively, and were either higher or lower

Table 2. The emitter data supplied by the manufacturers.

Emitters	Outer diameter (mm)	Inner diameter (mm)	Emitter spacing (cm)	Operating pressure (kPa)	Manufacturer flow rates (l h^{-1})	Measured flow rates (l h^{-1})
A1	16	14.2	40	100	2.0	1.96
A2	16	14.2	40	100	4.0	3.7
A3	20	18.2	33	100	4.0	3.75
B1	16	14.8	20	100	3.0	2.7
B2	16	14.8	90	100	2.4	2.2
C1	16	14.2	30	100	1.1	1.02
C2	16	14.2	30	100	2.5	2.26
D1*	16	13.8	25	250	3.8	3.84
D2*	16	13.8	25	250	3.8	2.2
t-statistic					0.71	
t-critical (α = 0.05)					2.11	

* Compensating emitters.

Table 3. The emitter flow rate vs. pressure head data supplied by manufacturers.

	Emitter flow rate (l h^{-1})				
Emitters	50 kPa	100 kPa	150 kPa	200 kPa	250 kPa
A1	1.3	2.0	2.4	2.9	-
A2	2.6	4.0	4.8	5.6	-
A3	2.6	4.0	4.8	5.6	-
B1	1.8	3.0	4.0	-	-
B2	1.4	2.4	3.2	-	-
C1	0.8	1.1	1.3	1.5	-
C2	1.8	2.5	3.0	3.5	-
D1*	3.9	3.7	3.6	3.7	3.8
D2*	2.1	2.0	2.1	2.2	2.2

* Compensating emitters

than manufacturers' reported values. Both compensating and non-compensating emitters showed higher correlation coefficient (r) values ranging from 0.958 to 0.999 (Table 4). The emitters' flow regimes were classified based on their exponents (x) values (Boswell, 1985) and the compensating emitters had near zero values, as expected. The emitter exponents ranged from 0.60 to 0.85 and 0.02 to 0.05 for non-compensating and compensating emitters, respectively (Table 4). Five out of the 7 non-compensating emitters evaluated in this study (A1, A2, A3, C1 and C2) had a turbulent flow regime based on the Bralts et al. (1981) classification. However, 2 of them (B1 and B2) had a transition flow regime between turbulent and laminar. The results showed that the compensating emitters' emitter exponents were as expected (higher x values for the non-compensating emitters showed that the flow rates of non-compensating emitters had sensitivity to pressure variation in the system higher than those of compensating emitters). Figure 1 showed that measured emitter flow rates of the non-compensating emitters varied under different pressure heads, as indicated by Bralts et al. (1981) and Özekici and Bozkurt (1999).

According to Bralts and Wu (1979), theoretically the compensating drip emitters' discharges should not show any variation under different pressures, but they should be constant under variable pressures. However, in accordance with some other studies (Madramootoo et al., 1988; Özekici and Bozkurt, 1999), our results did not support that theory (Figure 2).

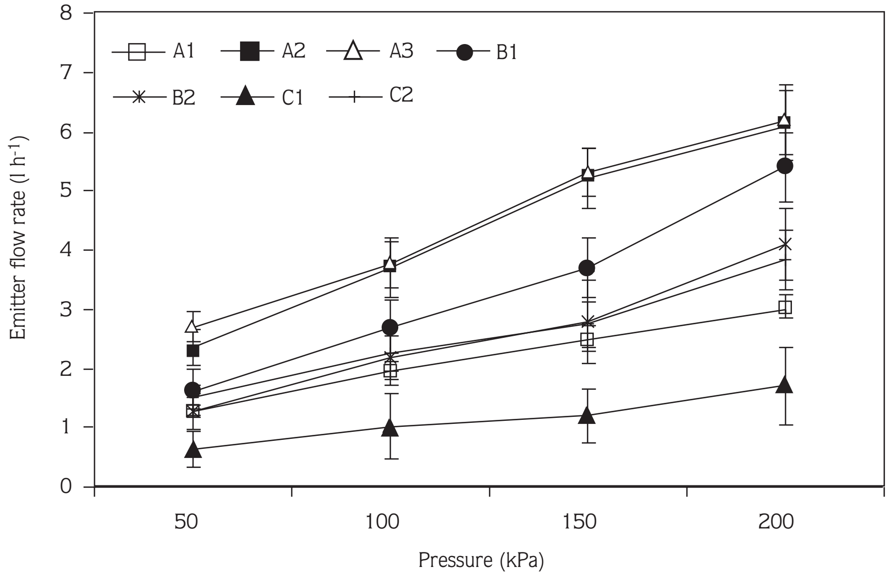

Figure 1. Measured emitter flow rates under different pressure heads for the non-compensating emitters. The same capital letters with different numbers imply the same specific commercial firm with different kinds of non-compensating laterals. Bars denote standard errors of the mean.

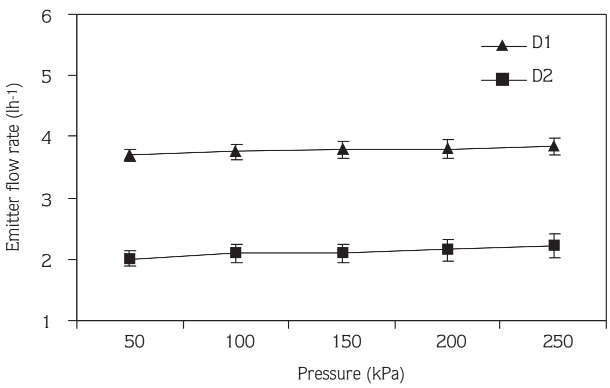

Figure 2. Measured emitter flow rates under different pressure heads for the compensating emitters. The same capital letters with different numbers imply the same specific commercial firm with different kinds of non-compensating laterals. Bars denote standard errors of the mean.

Table 4. Measured values of x, k, r, and CV_m (CV_m values presented are at 100 kPa for non-compensating emitters and 250 kPa for compensating emitters).

Emitters	x	k	r	CV_m (%)
A1	0.6188	0.4699	0.999	33.9
A2	0.7010	0.7556	0.998	38.1
A3	0.6122	0.9803	0.992	34.7
B1	0.8501	0.3949	0.992	48.0
B2	0.8043	0.3449	0.991	45.4
C1	0.6546	0.2236	0.985	37.7
C2	0.6437	0.5200	0.986	37.9
D1*	0.0222	3.5684	0.983	1.4
D2*	0.0576	1.8224	0.958	3.8

* Compensating emitters

Özekici and Sneed (1995) and Özekici and Bozkurt (1999) stated in their studies that the CV_m values of the compensating emitters were higher than those of non-compensating emitters, because it was difficult to manufacture the movable parts in the compensating emitters. However, in contrast to Özekici and Sneed (1995) and Özekici and Bozkurt (1999), our results indicated higher CV_m values for non-compensating emitters than those of compensating ones. This implied that our results were in agreement with other researchers' conclusions (e.g., Bralts et al., 1981; Decroix and Malaval, 1985; Madramootoo et al., 1988), except for those of Özekici and Bozkurt (1995) and Özekici and Sneed (1995). Average non-compensating and

Table 5. The values of manufacturer's coefficient of variation (CV_m) of the emitters under different pressure heads.

	CV_m (%)				
Emitters	50 kPa	100 kPa	150 kPa	200 kPa	250 kPa
A1	32.5	33.9	29.5	33.2	28.9
A2	35.5	38.1	41.1	34.6	38.6
A3	33.4	34.7	30.9	35.1	34.8
B1	47.5	48.0	48.3	48.6	49.7
B2	42	45.4	45.8	47.9	46.1
C1	38.5	37.7	36.8	35.9	37.4
C2	39	37.9	37.5	36.2	37.5
D1*	1.3	1.6	1.5	1.2	1.4
D2*	4.0	3.9	3.5	3.6	3.8

* Compensating emitters

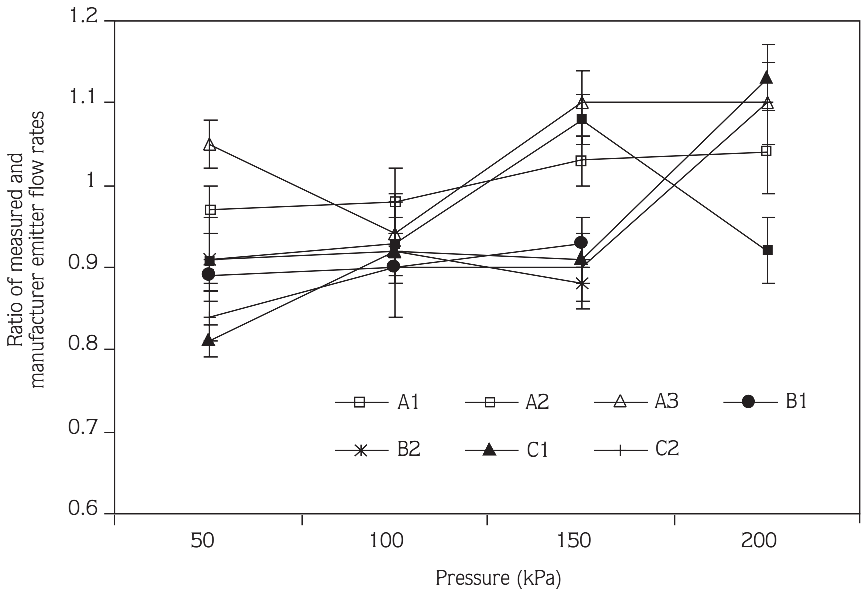

Figure 3. Ratio between measured and given emitter flow rates by manufacturers under different pressures for the non-compensating emitters. The same capital letters with different numbers imply the same specific commercial firm with different kinds of non-compensating laterals. Bars denote standard errors of the mean.

compensating emitters' CV_m values under 100 kPa were 39.38% and 2.75%, respectively (Table 5). Overall, there was no systematic pattern in all emitters' CV_m values, indicating no obvious regular increase or decrease in CV_m values with increases in pressure. Measured CV_m values of the non-compensating emitters were classified as unacceptable based on ASAE standards (1996). This implies that there is no possibility of uniform water distribution with the tested non-compensating emitters. On the other hand, the compensating emitters' CV_m values were <5% and were classified as excellent under all pressure head variations.

Only 1 (A1) out of the 7 non-compensating emitters had expected results in discharge rates. The other 6 non-

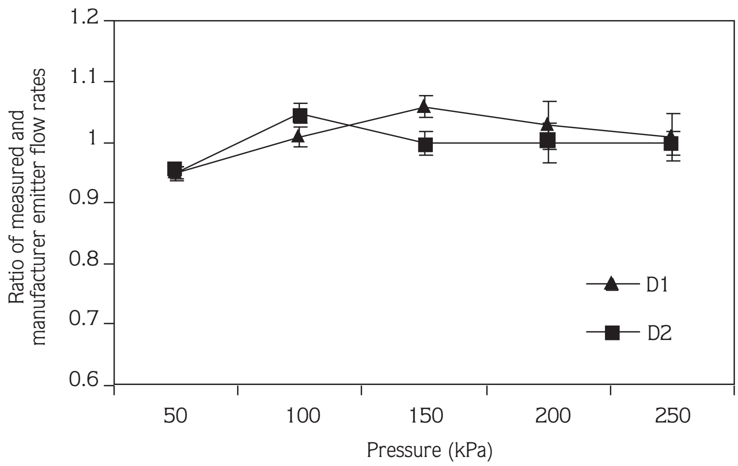

Figure 4. Ratio between measured and given emitter flow rates by manufacturers under different pressures for the compensating emitters. The same capital letters with different numbers imply the same specific commercial firm with different kinds of non-compensating laterals. Bars denote standard errors of the mean.

compensating emitters had more than 20% deviation from the mean discharge (Figure 3). On the other hand, the 2 compensating emitters showed less than ± 5% variation from the mean discharge (Figure 4). For compensating emitters, emitter flow rate fluctuations under higher pressures (200 and 250 kPa) were more constant compared to those under lower pressures (50, 100, and 150 kPa) (Figure 4). According to Braud and Soon (1980), a general rule for arid area uniformity is to limit the discharge variation in a lateral line to 10% of the average discharge. Emitters with a discharge exponent of 0.5 would translate into 20% pressure variation.

Conclusion

Unlike other irrigation systems, water is applied to a restricted soil profile under trickle irrigation. The productivity of a crop is directly related to the amount of water it receives, and irrigation therefore needs to be as uniform as possible. The uniformity of a micro-irrigation system is affected not only by hydraulic design but also by manufacturer's variation. One way to increase irrigation water use efficiency in the Harran plain is to use emitters with lower manufacturer's variation in the design of drip irrigation systems. A lower CV_m helps one to obtain a better uniform water application in the field.

Test results showed that non-compensating emitters widely used in the region had very high manufacturer's variations that are classified as unacceptable. The compensating emitters tested were excellent. In the design of micro-irrigation systems, one should always be careful regarding the use of data supplied by manufacturers. Based on test results from widely used emitters in the region, farmers might be encouraged to use compensating emitters instead of non-compensating emitters. As an alternative, if farmers would prefer to use non-compensating emitters because of the high cost of compensating emitters then the following suggestions should be considered: (1) the laterals should be kept short, (2) optimum operating pressures should be used based on manufacturers' suggestions, and (3) different manufacturers' products with better qualities should be selected and brought to the region.

Currently, since there is no shortage of irrigation water in the Harran plain, the importance of irrigation application uniformity is not well understood by farmers. However, farmers in the region may experience water shortages in the near future and that will certainly make uniform irrigation water application a very important issue. Therefore, drip irrigation systems used in the region need to have high CV_m values reducing water, nutrient and energy losses.

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