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Pressure Compensated Micro Sprinklers: A Review

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***Abstract*— Water is a scarce, limited and precious resource and one of the costliest inputs in agriculture and horticulture. Most of the irrigation is by open flow systems having relatively low efficiencies of water application. Due to scarcity of water and latest advancements in technology, farmers have started using micro irrigation systems i.e. drips and micro sprinklers. Micro sprinklers are a modification of conventional sprinklers and drip The success of micro-irrigation depends on the capacity and the ability of the system to optimize distribution of water resulting in high yields and better quality. The micro-irrigation system has complete adaptability to automation. Hence it is needed to know the performance of different micro-sprinkler systems at changing pressure heads and at different overlaps. The success of micro-irrigation depends on the capacity and the ability of the system to optimize distribution of water resulting in high yields and better quality. The micro-irrigation system has complete adaptability to automation. Hence it is needed to know the performance of different micro-sprinkler systems at changing pressure heads and at different overlaps.**

Keywords— Micro Sprinklers; Distribution Uniformity; Emission Uniformity; Statistical Uniformity; Uniformity Coefficient

I. INTRODUCTION

There are different type of irrigation systems adopted in the field as per requirements of crops, soil, and availability of water. Mechanization requires irrigation also to be efficient and savings in water consumption. There are three principle methods of irrigation viz. 1) Surface 2) Sub surface 3) Aerial, overhead or sprinkler irrigation. Micro-irrigation is the method in which low volume of water is applied at low pressure and high frequency usually an irrigation interval is in the ranges of 1 to 4 days [1]. It is adopted by using drips, micro-sprinklers, micro tubes. The term "micro-irrigation" describes a family of irrigation systems that apply water through small devices. These devices deliver water onto the soil surface very near the plant or below the soil surface directly into the plant root zone. Micro irrigation systems have been widely used in horticultural production and in landscape irrigation [2]. Micro-irrigation systems are immensely popular not only in arid regions and urban settings but also in sub humid and humid zones where water supplies are limited or water is expensive. In irrigated agriculture, micro-irrigation is used extensively for row crops, mulched crops, orchards, gardens, greenhouses and nurseries. In urban landscapes, micro-irrigation is widely used with ornamental plantings [3]. In drip irrigation the required quantity of water is applied by means of mains, sub mains, manifolds & plastic laterals in the with equally spaced emitters usually laid on the ground surface at low pressure & at low discharge at the root zone of the crop. Components of drip irrigation system are- 1) Head- 2) Main line and sub line- 3) Lateral lines- 4) Drip nozzles/Emitters or Drippers- 5) Control valves (Ball valves)- 6) Flush valves- 7) Air release cum vacuum breaker valves- 8) Non return valves- 9) Pressure gauge- 10) Grommet and take off, 11) End capes (end sets), 12) Filter [2]. Micro sprinklers are a modification to conventional sprinklers and drip. Presently, micro sprinklers are being preferred in place of drippers because of its various advantages such as high discharge rates which reduce the time of operation, increase in wetting diameter, quick and easy detection of faults, less clogging problem etc. In a Micro Sprinkler System the emission device is a small plastic jet or sprayer designed to provide water at 10 to100 l/hr over a wetted diameter of 2 to 10 m. Micro sprinklers require a slightly lower level of filtration (120 mesh) than an emitter or tape system. The main advantage to a micro sprinkler system is that water can be applied to a larger area than with an emitter or tape system. It is now possible to combine small flow regulators that convert each sprayer into a pressure compensated outlet. This can reduce the flows and system costs and deliver better uniformity. Weatherproof plastic materials ensure long term resistance to harsh conditions and agrochemicals. Micro-sprinklers are emitters commonly known as sprinkler or spray heads. There are several types .The emitters operate by throwing water through the air, usually in predetermined patterns. Depending on the water throw patterns, the micro-sprinklers are referred to as mini-sprays, micro-sprays, jets, or spinners. The sprinkler heads are external emitters individually connected to the lateral pipe typically using "spaghetti tubing," which is very small (1/8 inch to 1/4 inch) diameter tubing. The micro sprinkler heads can be mounted on a support stake or connected to the supply pipe. Micro-sprinklers are desirable because fewer heads are necessary to cover larger areas. The flow rates of micro-sprinkler emitters vary from 10 lph to 100 lph depending on the orifice size and line pressure. Micro-irrigation systems routinely achieve design emission uniformities (EU) of over 90% on fields that have great variability in length of run or terrain. Excellent design EU's may be achieved with both pressure compensating (PC) and non-pressure compensating (non-PC) drip tape, drip line, online emitters, sprays and micro-sprinkler emission devices using proper hydraulic design. In many cases, PC devices are preferred due to superior performance [4].

II. EVALAUTION AND TESTING

A. General

As per available information on testing, the Center for Irrigation Technology (CIT) - California State University, routinely tests drip emitters and micro sprinklers .The CIT performs three types of tests on drip emitters and micro sprinklers as follows [1] [2]:

- Discharge vs. Pressure - The emitters are tested over a range of pressures.
- Discharge vs. Temperature - The emitters are tested at a single pressure over a range of temperatures.
- Coefficient of Manufacturers Variability - The emitters are tested at a single pressure.

For all three types of tests, the Coefficient of Uniformity (CU), Emission Uniformity (EU), and Manufacturers Variability (Cv) are calculated for each pressure tested. In India, M/s Jain Irrigation Ltd, Jalgaon has some facility for testing their micro sprinklers. Some work has been carried out at the IIT Kharagpur as well as at the GB Pant University of Agriculture and Technology, Pantnagar. But at all these places only micro sprinklers have been tested (pressure compensated devices as well as overlaps have not been considered).

B. Pressure – Discharge relationship

Pressure discharge relationship was described using the following relationship [5].

$$Q = K\ P^x$$

Where,

Q = flow rate, lph

K = characteristic nozzle discharge coefficient

P = pressure applied, kg/cm^2

x = nozzle exponent characterizing the nozzle flow regime

C. Emission Uniformity

Emission uniformity (EU) has been generally used to describe the flow variation from emitting device. The discharge collected at each emitting device was used for determination of emission uniformity. Following equation to compute emission uniformity was suggested [5].

$$EU = 100\ qn / qa \qquad (1)$$

Where ,

EU = emission uniformity, percent

qn = average of the lowest !/4 th of the emission point discharge for field data, lph

qa = average emission point discharge of test sample operated at the reference pressure head, lph

D. Uniformity Coefficient

Christiansen [6] suggested the following equation for computing the uniformity coefficient

$$CUC = 100\ (1.0 - \sum X\ \ / m\ n) \qquad (2)$$

Where,

CUC = uniformity coefficient, percent

X = numerical deviation of individual observed depth from average depth, mm

m = average depth of all observations, mm

n = total number of observation points

This parameter considers deviations by magnitude alone without reflecting on excess or deficit. In practice, one of the two may be more critical. Many researchers have computed and interpreted the uniformity for various irrigation systems [7] [8] [9].

E. Distribution Uniformity

Distribution Uniformity (DU) indicates the degree to which the water is applied uniformly over the area and is determined by using the following relationship

$$DU = \frac{\text{Average low quarter depth of water caught}}{\text{Average depth of water caught}} \qquad (3)$$

The values of DU above 0.7 are considered as acceptable [10].

F. Wilcox-Swaile's Coefficient of Uniformity

Wilcox-Swailes Coefficient of Uniformity (WSCU) was proposed based upon the coefficient of variation, which can be expressed as:

$$WSCU = (1 – CV) \qquad (4)$$

Where, CV is Coefficient of Variation expressed in fraction, as the standard deviation divided by mean value of emitter discharges (or the mean and the standard deviation of the sum of discharges of all emitters at each plant for plant wise WSCU) [11]. This parameter has the same limitation as the CCU.

G. Statistical Uniformity

The uniformity of irrigation through the terms Statistical Coefficient of Uniformity (SCU) and Low Quarter Distribution Uniformity (SDU_{lq}) could also be described [12] [13], which are expressed as:

$$SCU = (1 – \sqrt{2/\pi}\ CV) \qquad (5)$$

$$SDU_{lq} = (1 – 1.27\ CV) \qquad (6)$$

The reason for the use of term 1.27 in Eq (6) due to the fact that in a normal distribution, the mean of the low quarter of the values occurs approximately 1.27 times the standard deviation below the mean [13]. These parameters were used by many workers [14] [15]. While SCU has the same limitation as the CCU, SDU_{lq} reflects on the deficit of water in the lower quarter of the area if each dripper represents the same area.

H. Coefficient for Emitter Flow Variation

Coefficient for Emitter Flow Variation (CEFV) has been used which can be measured both plant and emitter wise from the field observations [16]. It is expressed as:

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$$CEFV = \frac{0.667\left(\sum US - \sum LS\right)}{\left(\sum US + \sum LS\right)} \quad (7)$$

Where,

ΣUS is the sum of observations in upper 1/6th of distribution, and

ΣLS is the sum of observations in lower 1/6th of distribution.

Computed values of actual Coefficient of Uniformity (CU) were obtained from CEFV using the following equation described by as CU (CEFV) [7] [9] [16] [17] [18].

$$CU(CEFV) = (1 - \sqrt{2/\pi}\ CEFV)) \quad (8)$$

The values of the computed CUs are theoretically similar to that of CCU when the data follow a normal distribution. Therefore, a comparison between CCU and the computed values of CU (CEFV) were made to assess whether under our experimental set up CU could be calculated using CEFV at reduced cost on observations [9] [18].

Modified expression for use with centre pivot catch-can data was proposed [19], as Eq(9) and modified to include a term representing the distance from the centre to the catch-can, Ss. The modified Heermann-Hein CUHH equation is given later [20].

$$CU_{HH} = 100\left(1 - \sum_n S_s \left|D_s - \frac{\sum_n D_s S_s}{\sum_n S_s}\right| / \sum_n D_s S_s\right) \quad (9)$$

I. Emission and Distribution Uniformity

The emission uniformity is used to characterize the uniformity of micro-irrigation systems [21] has been cited by many researchers [7] [8] [21] [22].

$$EU = \left(1 - 1.27\frac{CV_M}{\sqrt{n}}\right)\left(\frac{Q_{lq}}{Q_{avg}}\right) X\ 100\% \quad (10)$$

Where, CV is Coefficient of Variation as expressed above in fraction [22].

$$DU_{lq} = \frac{d_{lq}}{d_{avg}} \quad (11)$$

$$DU_{lq} = \frac{average\ low\ quater\ depth}{average\ depth\ of\ water\ accumulated\ in\ all\ emitters} \quad (12)$$

III. Experiments on Sprinklers and Micro Sprinklers

Effect of pressure variation in micro sprinkler irrigation was reported for a fixed stake height of 0.2m with pressures (H) of 1.0,1.2 , 1.1.4,1.6, 1.8, 2.0,2.2,and 2.6 kg/cm^2 [23]. And found that the pressure discharge relationship of form Q= aH^b developed for all the micro sprinklers under study.

Benefits of pressure compensated (PC) micro irrigation emission devices were discussed and evaluated [4]. Micro-Irrigation systems routinely achieve design emission uniformities (EU) of over 90% on fields that have great variability in length of run or terrain. Excellent design EU's may be achieved with both pressure compensating (PC) and non-pressure compensating (non-PC) drip tape, dripline, online emitters, sprays and micro-sprinkler emission devices using proper hydraulic design. However, in many cases, PC devices are preferred due to superior performance. Until recently, PC devices commanded a substantial price premium over non-PC devices which limited widespread adoption. But due to manufacturing innovations over the past decade, high performance PC driplines are now available at a marginal price premium compared to non-PC driplines, which has resulted in their widespread adoption compared to non-PC driplines. The same is expected to occur for drip tapes through manufacturing innovations that are expected to create higher performance PC drip tapes that command only a marginal price premium vs. currently available PC and non-PC drip tapes [4]. As widespread adoption takes place, significant benefits are expected as a result of improving irrigation uniformity with PC.

Hydraulic studies were conducted on five different microsprinklers (Non-PC) at operating pressures of 0.5, 1.0, 1.5, 2.0 and 2.5 kg/cm^2, at four different spacings of 1.5mX1.5m, 2mX2m, 2.5mX2.5m, 3mX3m and at a fixed riser height of 0.3m and found the relationship between the operating pressure and discharge of a micro sprinkler to be power or logarithmic or linear correlation [24].

Performance of rotating spray plate sprinklers were tested, evaluated and reported with five different types of spray nozzles, used on center pivot irrigation system [25]. Several outdoor single-sprinklers and overlapped - sprinklers irrigation tests were conducted for determining: water application rate, uniformity of water distribution, and application efficiency. The uniformity (CU) values were calculated by integrating each row of collector data to obtain an average rate (relative application depth) for each row, and using these four values to calculate the "Christiansen uniformity". The uniformity Coefficient (CU) was calculated by using the Christiansen formula [6] [26] [27].

The water distribution under micro-sprinklers in laboratory was studied for two types of micro-sprinkler heads, spinner micro-sprinkler and rotating micro-sprinkler under the experimental conditions at three rates of discharge 40, 70 and 100 l/h for spinner type, 50, 100 and 200 for rotating type 100, 150 and 250 l/h for rotating type and four working pressure ranges of 1, 1.5, 2 and 2.5 bar and nozzle heights above the ground 20, 40, 60 and 90cm respectively [28]. The results indicated that the water distribution pattern of micro-sprinklers follows triangular shape for both types of micro-sprinkler heads, and that the wetted radius has a direct relationship with the discharge rate, working pressure and nozzle heights [28]. The highest Christiansen uniformity coefficient and distribution uniformity were achieved within 2 Bar operation pressure for both types and 20 cm and 40 cm nozzle heights for spinner and rotating types respectively.

The performance of rotating sprinklers and its evaluation for landscape irrigation were discussed along with the water conservation potential [29].

A methodology was discussed for determination of optimum design parameters of a micro sprinkler or micro jet (Non pressure compensated) in the experiments which were conducted in a closed area [30]. The independent parameter such as input pressure and stake height were varied and dependent parameter such as discharge, effective radius, average depth of water and the Coefficient of Uniformity of a single emitter were evaluated. The stake heights (risers) were kept at 0.4, 0.5, 0.6 and 0.7m and the experiments were conducted art 7.5, 10.0, 12.5 and 15.0 N/m^2 pressure. Coefficient of uniformity of single emitter (CU) varied from 34.87 to 54.75 for the stake height of 0.30m, 38.81 to 58.25 at the stake height of 0.40 m, from 42.26 to 55.44 at the stake

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height of 0.50 m, from 53.07 to 67.01 at the stake height of 0.60 m and from 46.65 to 68.14 at the stake height of 0.70 m at different pressures [30]. Similar testing of micro sprinklers was conducted at 0.5, 1.0, 1.5 and 2.5 kg/cm^2 pressure and for four heights (20, 35, 50 and 65 cm) [31] [32]. However this study was limited to single applicator (Non-pressure compensated) while the overlaps were not considered [31] [32].

The irrigation performance of rotating spray plate sprinkler in different mobile irrigation machines could be changed with the characteristics of the spray plate sprinklers, overlapping spacing, and machine speed [33]. The precipitation rate (mm/h) is a key factor in the evaluation of irrigation. Selection of sprinkler head or spray nozzle plays an important role in the performance of modern irrigation machines performance.

Micro jets (classified as non-pressure compensating) were evaluated with respect to pressure–discharge relationship, emission uniformity, wetting diameter. These parameters were determined for different combinations of pressures ranging from 0.5 to 1.7 kg/cm^2 and stake heights of 0 to 10 cm. The emission uniformity was found to be more than 90%. The wetting diameter increased with increase in operating pressure and stake height of micro jets [10].

The uniformity of flow for the emitter and spaghetti tubing of micro sprinklers were evaluated [34]. Micro-sprinkler assembly discharge variations were examined to partition contributions from the spaghetti tubing and the emitter. The coefficients of variation (CV) of the emitter alone were found to be excellent (less than 2%) for the two models tested. Variations in 0.61 m lengths of spaghetti tubing ranged from 2 to 7.6%. Spaghetti tubing diameter was found to significantly affect discharge rate at 138 kPa system operating pressure. An increase of 12 per cent in discharge rate from Micro-Bird II Spinners resulted when spaghetti tube diameter increased from 4 mm. to 6mm. The discharge rate increased by 60% for Micro-sprinkler III emitters when 10 mm tubing was used instead of 4mm tubing. Spaghetti tubing was found to be an important factor to consider in the overall uniformity of micro sprinkler systems. The efficiency of micro irrigation systems is significantly affected by the uniformity at which water is discharged from the emission devices throughout the system. Factors which may affect the uniformity of discharges from emitters include pressure differences within the system due to friction or elevation changes, inherent emitter characteristics due to their design, the unit-to-unit variation of emission devices during manufacture, and partial or full plugging of the emitters from particles, insects or organic growth [35]. The purpose of micro irrigation is to apply water relatively frequently at low application rates. Small differences in individual emitter discharges can be magnified when irrigations are made on a daily basis and the deviations accumulate. Therefore, it is essential that emitter flow variations be minimized so efficient water utilization can be promoted. Stake assemblies were connected to the supply system with barbed adapters. A 100 mm diameter PVC pipe was placed over the emitter and stake assembly to confine discharge and direct it into a 19-L plastic container.

The knowledge of drop size distribution from medium-sized agricultural sprinklers has its importance for two reasons. First the small droplets are subject to wind drift, distorting the application pattern. Second large droplets possesses greater kinetic energy which is transferred to the soil surface causing particle dislodgement and puddling that may result in surface crusting and run-off. The drop size distributions from medium-size agricultural sprinklers were measured to study the effects of pressure and nozzle size on the distributions [36]. Droplet size was measured by the flour method. Circular pans 21 cm in diameter and 2 cm deep were filled with fresh, bleached wheat flour by shifting and carefully struck off with a straight edge. The pans of flour were never allowed to stand more than two hour before exposure to the sprinkler spray. After exposure, the pans of flour were dried for twenty four hour at 38°C. A sample of diameter of 18.3 cm was taken from the center of the pans to avoid droplets that might have been cut by the sharp edge of the pan. This sample was placed on a 50 mesh sieve and shaken on a reciprocating shaker to separate the dough balls from the flour. The dough balls were separated by sieving using a set of 16 sieves of US series 5 to 50 mesh sieve sizes and weighed. The effect of nozzle size on the drop size distribution was smaller than that of pressure [36]. Decreasing nozzle diameter decreased mean drop size, but increasing pressure decreases mean drop size by a greater amount. Similar studies were also reported at low pressure [37], rotating spray [38] and the problem associated in measurement of the droplet distribution using laser unit [39].

The design of a network of micro system starts from the evaluation of hydraulic parameters of emitters to be used in the system. The research has been carried out on application part of micro sprinklers in vegetable crops in small plots of at best 5m X 5m or 10m X 10m [30]. But while irrigating large fields (in ha) it has been often reported that water does not reach the farthest distances due to the improper hydraulic design of the system [40] [41]. Pressure applied at the upstream end is generally calculated on thumb rules, without proper consideration of the optimum design parameters of the emitters [40], [42].

Further, plant needs different elements to grow and thrive. Absence or inadequacy of any nutrient limits the plant growth. The purpose of applying fertilizer is to provide a balanced dose of nutrients needed by the plant to grow and yield adequately. Fertilizer is applied either by broadcasting method or introducing it into irrigation system along with the irrigation water. The application of fertilizer through the micro irrigation system is called fertigation. It is the most advance and efficient practice of fertilization. It combines the two main factors in plant growth and development *i.e.*, water and nutrients. The right combination of water and nutrients is the key for high yield and quality of produce [43]. In fertigation, fertilizer application is made in small and frequent doses that fit within scheduled irrigation intervals matching the plant water use to avoid leaching. Significant savings in the use of fertilizers and increase in yield have been reported by different researchers [43]. Although liquid fertilizers are most appropriate for use in fertigation. But in India the lack of availability and high cost of liquid fertilizers restricts their use for fertigation. Experiments with granular fertilizers also established their feasibility and revealed significant fertilizer savings and increase in the yields of onion, okra and tomato.

The success of micro-irrigation depends on the capacity and the ability of the system to optimize distribution of water and nutrients thus resulting in high yields and better quality. The micro-irrigation system has complete adaptability to automation. Therefore it is needed to know the performance of different micro sprinkler systems at changing pressure heads and heights of risers. Not only this, the overlapping is also significant *vis-à-vis* distribution uniformity.

IV. DISCUSSIONS

There is a challenge to increase food supplies by at least 40% in the next 50 years, due to growing populations and changing preferences. Increased productivity should not come by expansion of water but by increased productivity of existing sources. That can be achieved through reform of water design and management systems. Irrigation was the source of more than 50% of the increase in global food production during 1965-85 [44] and more than 60% of the value of Asian food crops come from irrigated land [45]. Uniform water distribution from micro irrigation is necessary to maximize the crop yields and to improve the quality of produce. The uniform water distribution is also necessary for efficient use of available irrigation water [46] [47] [48]. For this reason the emission uniformity and uniformity coefficient may always be taken as design variables for micro irrigation system. For having an acceptable irrigation pattern the information regarding wetting diameter at different operating pressures is required, since it determines the optimum overlap to be provided when system is operated under actual field conditions.

The results of various studies are summarized in table below to identify some of the research gaps.

TABLE I. SUMMARY OF RECENT WORKS ON MICROSPRINKLERS

S. No.	Ref	Area of work
1	[3]	Micro irrigation and suitability of different irrigation pumps
2	[4]	The paper describes the benefits of pressure compensation for both the drip and micro sprinklers
3.	[10]	Performance evaluation of micro jets ;pressure –discharge relationship, emission uniformity, wetting diameter for different combinations of pressures ranging from 0.5 to 1.7 kg/cm^2 and stake heights of 0 to 10cm.
4.	[23]	Reported on effect of pressure variation in micro sprinkler irrigation at a fixed stake height of 0.2m with pressures of 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2 and 2.6 kg/cm^2.
5.	[24]	Hydraulic studies of five different microsprinklers (NPC) at operating pressures of 0.5, 1.0.1.5,2.0, and 2.5 kg/cm^2 , a four different spacings 1.5mX1.5m, 2mX2m, 2.5mX2.5m, 3mX3m at a fixed riser height of 0.3m
6.	[25]	Reported on performance of rotating spray plate sprinklers, used on center pivot irrigation system, were conducted for the spray nozzle heights above the soil surface (1.0, 1.50,and 2.0 m), under different operating pressures (0.10, 0.15, 0.20 MPa) were studied on the application efficiency and uniformity of water distribution using three types of spray nozzles (i.e. rotator, spinner and wobbler)
7	[28]	Studied two types of micro-sprinkler heads, spinner micro-sprinkler and rotating micro-sprinkler at working pressures of 1, 1.5, 2 and 2.5 bar and nozzle heights above the ground 20, 40, 60 and 90cm
8.	[29]	Performance and water conservation potential of multi-stream, multi trajectory rotating sprinkler for landscape irrigation
9	[30]	A method for determination of optimum design parameters of a micro sprinkler or micro jet. Stake heights (Risers) selected were 0.40m, 0.50m, 0.60m and 0.70m and the pressures were 7.5 N/m^2 , 10.0 N/m^2, 12.5 N/m^2, and 15 N/m^2.
10.	[31]	Reported testing for distribution patterns of various micro-sprinklers (NPC), and uniformity measures of micro sprinklers at 0.5, 1.0, 1.5 and 2.5 kg/cm^2 pressure and for four heights (20cm, 35cm, 50cm, and 65 cm).
11	[33]	Performance of rotating spray plate sprinkler. Selection of sprinkler head or spray nozzle plays an important role in the performance of modern irrigation machines. Two sprinkler heights, 1.0 and 1.5 m were used to evaluate the effect on the wetted diameter and the average precipitation rate. , a low pressure range of operation was selected of 100, 150 and 200 kPa
12.	[43]	Elements of micro-irrigation and its crop application effect on yield and water saving
13.	[50]	Defined simple pressure parameters for micro irrigation systems

Some research gaps, which need scientific interventions for precision in irrigation water application using pressure compensated micro-sprinklers.

1. Performance evaluation of micro sprinklers (PC) at different heights at different pressures and overlapping.
2. To develop functional relationship between pressure and discharge, at different overlapping and riser heights.
3. Evaluation of low hp pumps (0-5hp) with different energy drives for on farm irrigation
4. Field evaluation of micro sprinklers (PC) for different crops.

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