Agronomía Colombiana
ISSN: 0120-9965
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Universidad Nacional de Colombia
Colombia

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Agronomía Colombiana, vol. 35, núm. 3, septiembre-diciembre, 2017, pp. 350-356
Universidad Nacional de Colombia
Bogotá, Colombia

Effect of deficit irrigation on yield and quality of pear (*Pyrus communis* cv. Triumph of Vienna)

Efecto del riego deficitario en la producción y calidad de la pera (*Pyrus communis* L.) variedad Triunfo de Viena

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ABSTRACT

Crop demands for irrigation require different technologies to optimize the use of water. Regulated Deficit Irrigation (RDI) is a strategy that enables a significant reduction of water application without affecting the crop yield and quality, with the advantage of being a tool for control of vegetative growth. The present study was conducted in Sesquilé, Cundinamarca (Colombia) between 2015 and 2016. The objective was to evaluate the quality and development of pear crop (*Pyrus communis* L. cv. Triumph of Vienna) on field conditions, using three treatments of 100%, and 25% of water requirement (ETc) and no irrigation, applied at the rapid fruit growth stage. The mid day stem water potential, plant water relations, pressure-volume curve, fruit yield and quality were evaluated. There were no significant differences in the yield and quality of the fruits among the different irrigation treatments. The trees had the mechanisms of osmotic adjustment, which allowed water stressed trees to cope with irrigation restrictions during the rapid fruit growth stage without affecting the yield.

Key words: water savings, osmotic adjustment, water consumption, water relations, deciduous.

RESUMEN

La demanda de riego en los cultivos requiere diferentes tecnologías para optimizar el uso del agua. El Riego deficitario controlado (RDC), es una estrategia que permite una reducción significativa en la aplicación de agua sin afectar el rendimiento y la calidad del cultivo, con la ventaja de ser una herramienta para controlar el crecimiento vegetativo. El presente estudio se realizó en Sesquilé, Cundinamarca (Colombia) entre 2015 y 2016 con el objetivo de evaluar la calidad y el desarrollo del cultivo de pera (*Pyrus communis* L. cv. Triumph of Vienna) en condiciones de campo, utilizando tres tratamientos: 100%, 25% de requerimiento de agua (ETc) y sin riego, aplicados en la etapa de crecimiento rápido del fruto. Se evaluó el potencial hídrico del tallo del mediodía, las relaciones hídricas de la planta, la curva presión-volumen y el rendimiento y la calidad del fruto. No se presentaron diferencias significativas en el rendimiento y la calidad de las frutas entre los diferentes tratamientos de riego. Los árboles mostraron mecanismos de ajuste osmótico, lo que permitió a aquellos con estrés hídrico hacer frente a las restricciones de riego durante la etapa de crecimiento rápido del fruto sin afectar el rendimiento.

Palabras clave: ahorro de agua, ajuste osmótico, consumo de agua, relaciones hídricas, caducifolio.

Introduction

Worldwide, it is estimated that the total extraction of fresh surface water and groundwater for agricultural purposes is 69%, including irrigation, livestock and aquaculture (FAO, 2014). Around 50% of this water consumption corresponds to crop evapotranspiration (Kohli, *et al*., 2010) including fruit trees which are highly dependent on irrigation (Naor, 2006).

In Colombia, Boyacá is considered the most important area in production of deciduous fruit crops (pear, peach, plum and apple) About 5.382 ha were grown in 2010, which 31% relates to pear production. These crops continue their expansion, thus, it demands technological advances in the improvement of plant material, sanitary conditions, and irrigation techniques (Miranda *et al*., 2013).

The growers are conditioned by the available water that is scarce in some areas (De la Rosa *et al*., 2015), which makes it necessary to employ strategies to improve efficiency and optimize its use (Cui *et al*., 2009). Those strategies are based on the detection of plant response to water deficit (De Swaef*et al*., 2008) by means of indicators of plant and soil water status (water potential, sap flow, and trunk diameter

Received for publication: 25 April, 2016. Accepted for publication: 31 October, 2017

Doi: 10.15446/agron.colomb.v35n3.64313

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variation) to determine the best irrigation scheduling (Rallo *et al*., 2017).

Regulated deficit irrigation (RDI) has been widely used in deciduous and other fruit tree crops, such as citrus and grapevine (McCarthy, 2005) and consists of reducing water supply only in periods when fruit growth is less sensitive. The trees have shown various mechanisms of adaptation to water deficit, which usually imply osmotic adjustment, changes in tissue elastic properties, stress evasion by stomatal closure, and change in leaf area, amongst others (Torrecillas *et al*., 2001).

Several plant indicators have been considered as a tool for irrigation scheduling; one of the most used is the midday stem water potential (Ψ_t) (Intrigliolo and Castel, 2006). Based on this indicator, it is possible to know the plant water condition and its response to RDI. Techniques such as the Pressure-Volume (PV) curve are useful to determine if there is an osmotic adjustment due to water restriction (Mellisho*et al*., 2011).

The aim of this study was to evaluate the response of pear trees to water restriction and the influence of RDI during the rapid fruit growth stage on yield and quality of fruits in order to develop strategies to optimize the use of water on deciduous crops.

Materials and Methods

Location

The experiment was conducted from October2015 to April 2016, in an open field pear orchard (*Pyrus communis* L. cv. Triumph of Vienna) at the plot known as "Finca San Benito", located in Sesquilé, Cundinamarca (5°02' N and 73°47' W, elevation 2,595 m a.s.l.). Grafted pear trees of the cv. "Triumph of Vienna" with a well-developed root system were planted in 1998, in a spacing pattern of 4×4 m. All of them had similar management of pest and disease control, edaphic fertilization was applied twice a year and fertigation through the drip irrigation system every 15 d. The total amount applied was 60, 44, 100 k of N, and, respectively, using N32 liquid nitrogen (32%, N); 83% phosphoric acid (53%,); potassium nitrate (46% N, 13%). Additional applications of phosphorus, potassium and boron were performed.

The soil was identified as Histosol, with loamy and clay texture. The volumetric moisture at field capacity and at permanent wilting point was 26.9% and 15.3%, respectively. The content of organic matter, potassium and phosphorus were 5.06%, 78.2 and 23.9, respectively and pH was 4.6 (Molina *et al*., 2015).

Climate and Irrigation

The crop irrigation needs (ETc) were calculated according to Penman-Monteith method using a maximum crop coefficient (Kc = 0.8) at full canopy growth (Allen *et al*., 2006). The irrigation was applied through a drip system with two lines per row of trees and six 8 drippers per plant. Three treatments were applied from 60 to 140 d after full bloom (DAFB), corresponding to the rapid fruit growth stage (December 26, 2015 to March 9, 2016): (T1) Control in which the plants were irrigated at 100% of Etc, (T2) irrigation at 25% of T1 and (T3) no irrigation. During the rest of the season all plants were irrigated at 100% ETc. Weather conditions (temperature, relative humidity, precipitation, wind speed, solar radiation) were measured using an automatic weather station WS-GP1 (AT delta-T Devices Ltda., Cambridge, UK) located on the plot. The volume of irrigation water applied was measured with 12 mm volumetric counters Controlagua® (F.F. Soluciones S.A, Colombia). The accumulated volume of irrigation water applied during the treatments (60 to 140 DAFB) was 1460, 394, and 0 L per tree respectively in T1, T2, and T3.

Plant water relations

The midday stem water potential (Ψ_t) was measured every 8 d on two leaves of two trees in each replicate (16 leaves per treatment) selected from the inner part of the canopy, enclosed in an aluminum covered plastic bag during 90 min before the measurement with a pressure chamber (Model 600 Pressure Chamber Instrument, PMS Instrument Company, Oregon, USA) (Naor *et al*., 1995).

At mid-water restriction season (February 19, 2016), PV curves were performed according to the free transpiration technique (Tyree and Hammel, 1972) in order to determine the osmotic potential at the turgor loss point(Ψ_{oppt}), modulus of elasticity (ε), apoplastic relative water content (RWC_a) and relative water content at the turgor loss point (%RWC_{ppt}) (Mellisho*et al*., 2011). To obtain the curve, 20 leaves were cut per replicate and the petioles were immersed in distilled water for 24 h. Once saturated, the fresh weight of each leaf was measured with a precision electronic balance 0.1 mg (Precisa XT2202A, Dietikon, Switzerland) and then the leaf water potential (Ψ) was determined using the Scholander pressure chamber, finally, leave fresh weight was measured again. The procedure was performed successively at regular intervals as the leaves were dehydrated under ambient conditions until the minimum weight loss was found (Corcuera, 2003), then leaves were oven dried at 60° C for 72 h to determine the dry weight.

To find the osmotic potential at full turgor (Ψ_{100}) four saturated leaves were taken from each replicate and wrapped in aluminum foil and immediately frozen in liquid nitrogen in order to halt their metabolic activity (Abril, 2015). 72 h after, the tissue was macerated and centrifuged for 10 min at 10,000 rpm in order to extract the cellular fluids and determine Ψ_{100} using an Osmometer (Vapro®, Wescor, USA). The osmotic adjustment (ΔO) was estimated as the difference between Ψ_{100} of the plants of T2 Ψ_{100} and T3 and of the T1 Control treatment (Ruiz *et al*., 2000).

Yield and quality

All the fruits at physiological maturity were harvested from all the trees. Two fruits were randomly picked by treatment and replicate (8 fruits per treatment), to which they were determined: The higher (a) and minor (d) equatorial diameter and length (L) using a manual calibrator; fresh weight of each fruit using a precision balance 0.1 mg (Precisa XT2202A, Dietikon, Switzerland); the volume from the displacement of distilled water in a graduated 1,000 mL container; the color of the pulp and the peel using a colorimeter Chromameter CR-400 (Konica Minolta®, Japan); titratable total acids (TTA) using Titroline® 6000 (SI Analytics, Japan) automatic titrator with 0.1 N sodium hydroxide (NaOH); total soluble solids (TSS) with manual optical refractometer (Kikuchi Precision Optics, Tokyo, Japan); maturity index (IM) as the relationship: IM = , (Rodríguez *et al*., 2010) and firmness using 2 mm test with CT3 TextureAnalyzer (Brookfield Engineering Labs., USA) in the equatorial direction and at the poles of each fruit.

Statistical analysis

The experiment was carried out in a randomized block design with four replicates (12 plots with 12 to 20 trees each). Measurements were taken on two adjacent trees per replicate, considering the edge effect. Data were analyzed with ANOVA, and means were compared using Duncan's test at $P\leq0.05$ using the software InfoStat 2016 from InfoStat, FCA, Universidad Nacional de Córdoba, Argentina (Di Rienzo *et al*., 2016).

Results and Discussion

Climate and irrigation

During the study, the weather variables were measured. The minimum temperature, in January 2016 was 2.9°, and the maximum was 27.8°C, the mean was 14°C. The mean relative humidity was 81%, the highest was in April (98%) and the lowest was in January (60%). Mean ETo was 3.1 mm d^{-1}, a 14% lower than the maximum ETo recorded in the year (3.6 mm d^{-1}). The average vapor pressure deficit (VPD) was in the range of 0.62 (in January) to 0.03 (in April). The total precipitation during the restriction period was 218 mm (Fig. 1).

Plant water relations

The Ψ_t was influenced by precipitation. From 80 to 140 DAFB a significant difference was observed between T3 and other treatments according to Duncan's test ($P\leq0.05$), indicating that Ψ_t was a good indicator of the irrigation regimes applied. The Ψ_t had the same values for all three treatments at 150 and 170 DAFB due to rainfall. During the treatments, there was an increase of Ψ_t represented by more negative values in T3 (mean -1.17 MPa) than T2 (mean -0.9 MPa) and T1 (mean -0.9 MPa). T3 had a maximum of -1.78 MPa at 126 DAFB while there were no significant differences between T1 and T2, which means that the amount of

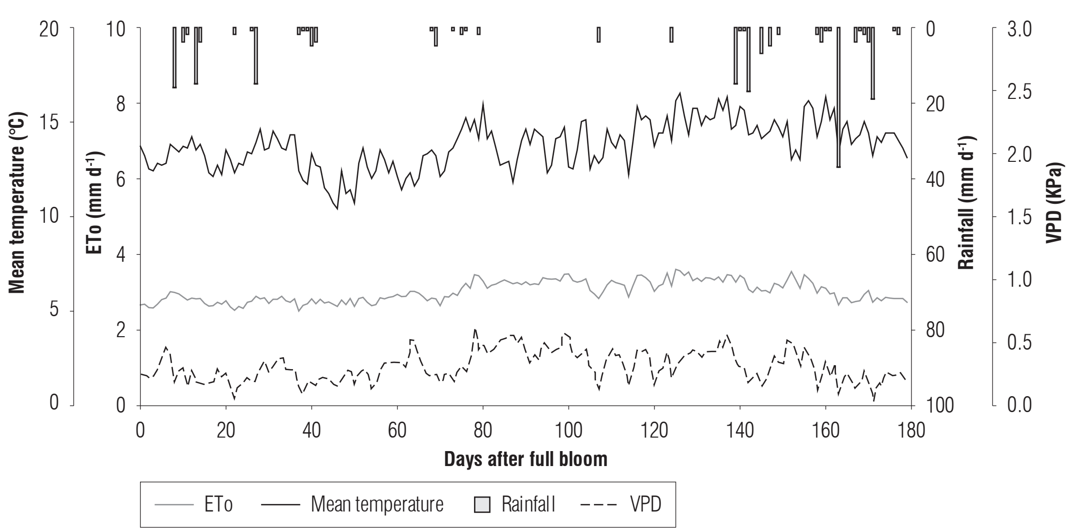

FIGURE 1. Climatic parameters during the crop cycle. Mean temperature, potential evapotranspiration (ETo), Rainfall and vapor pressure deficit (VPD).

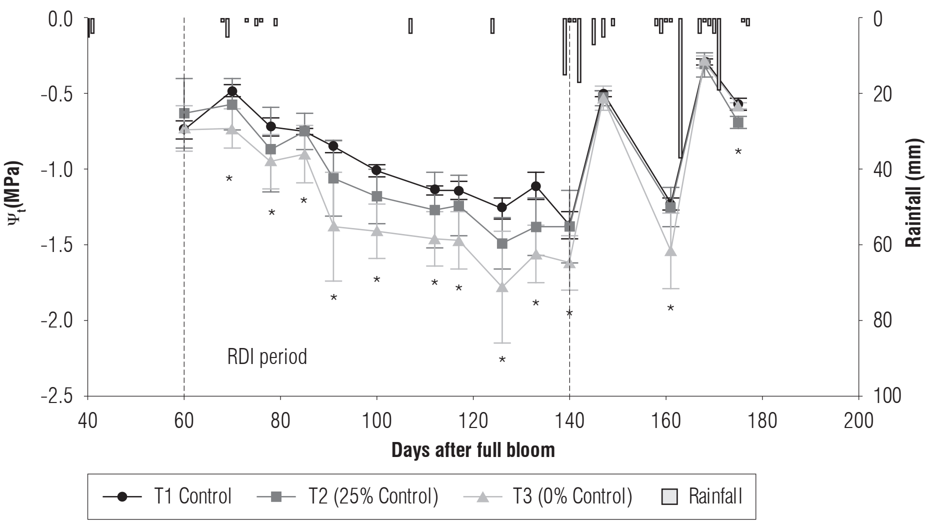

FIGURE 2. Variation of the midday stem water potential (Ψ_t) in T1, T2 and T3 obtained as the mean of 4 replicates per treatment and rainfall during the crop cycle. Bars indicate standard error and asterisks indicate significant difference between treatments.

water applied in T2 allowed to maintain water conditions of the plant similar to the Control (Fig. 2). Similar results in the same crop were reported by Abril (2015), with Ψ_t between -0.3 MPa and -1.22 MPa.

In other studies in pear, Caspari *et al.* (1994) reported more negative values of in trees variety 'Hosui' under water restriction (-2.0 MPa to -1.7 MPa), while Morandi *et al.* (2014) found values of Ψ_t between -0.6 MPa and -1.25 MPa for the 'AbbeFettel' variety, very similar to that reported by Marsal *et al.* (2002) (-0.5 MPa to -1.5 MPa) in pear 'Blanquilla' and Naor (2001) (-1.2 MPa and -3 MPa) in pear variety 'Spadona' under RDI treatments.

The Ψ_t was slightly higher in comparison to other species such as apricot (-1.08 MPa to -1.87 MPa) (Pérez *et al.*, 2014) and jujuba (-1 MPa and -4 MPa) (Cruz *et al.*, 2012). On the other hand, Ψ_t had a behavior similar to that reported by Samperio *et al.* (2015) in 'Red Beaut' plum (between -0.59 MPa and -0.70 MPa) and Podestá *et al.* (2010) who found a maximum Ψ_t of -1.53 MPa in cherry trees under water deficit.

At 119 DAFB (59 d of water restriction, the day on which the PV curve was performed) there was a significant difference that showed osmotic adjustment in Ψ_{100} between T3 and T1 (-3.1and -2.53 MPa, respectively). The greatest difference respect to Control was observed in the treatment T3 (0.57 MPa) that coincides with that reported in the apricot tree by Ruiz*et al.* (2000). The decrease in the osmotic potential can be attributed to the active solute accumulation on the leaf tissues which has been considered as a mechanism of osmotic adjustment in mature peach plants and depends on the species, variety, severity of water restriction, leaf maturity and the time in which the restriction was applied (Marsal and Girona, 1997; Cruz *et al.*, 2012).

The other parameters derived from the PV curve did not present a significant difference according to the Duncan's test ($P\leq0.05$) due to the treatments, similar to the results reported by Mellisho *et al.*, 2011 in peaches under water restriction where were no differences respect the Control in the turgor loss point (Ψ_{ppt}, WRC_{ppt}), or in de modulus of elasticity (ε), however they found osmotic adjustment of 0.18 MPa, that is lower than the values founded on this study.

It is important to note that these plants were under RDI treatments in previous years, which may have been preconditioned or affected (Ruiz*et al.*, 2000) causing their water status to be maintained. It is also observed that the increase of in Ψ_{100} T3 could contribute to maintain the turgor in the plant as observed in the values of Ψ_{oppt} (-5.9 MPa) and ε (11.5 MPa) slightly higher for T3.

Yield and quality

The harvested fruits were classified into three size categories according to diameter: category I larger than 65 mm, category II between 65 and 50 mm and category III less than 50 mm. Fruit yield per tree (kg/tree) was higher for T1 (23.59 kg) without significant difference with T2 and T3 according to the Duncan's test ($P\leq0.05$). The mean weight of the fruits was homogeneous between treatments with 160g, 170 g and 170 g for I, II and III respectively, it was similar to data found by Molina (2014) (140 g) and slightly lower than the reported by Abril, (2015) (200 g) in the same orchard. The number of fruits per tree varied between treatments

TABLE 1. Parameters of the pressure-volume curve for T1, T2 and T3 obtained as the mean of 4 repetitions per treatment and its standard error (S.E). Equal letters between columns indicate that there was no significant difference between treatments according to Duncan's test ($P \leq 0.05$).

	T3	S.E	T2	S.E	T1	S.E
Osmotic potential at full turgor (Ψ_{100})(MPa)	-3.1 b	0.08	-2.86 ab	0.11	-2.53 a	0.22
Apoplastic relative water content (RWC_a)(%)	89.51 a	1.54	90.54 a	3.14	90.46 a	2.03
Osmotic potential al turgor loss point (MPa) (Ψ_{oppt})	-5.9 a	2.93	-5.3 a	0.49	-5.02 a	0.60
Modulus of elasticity (ε) (MPa)	11.5 a	0.78	10.74 a	0.594	9.17 a	1.982
Relative water content at turgor loss point (%) (RWC_{ppt})	94.85 a	3.64	95.35 a	1.82	95.16 a	1.10
Osmotic adjustment (MPa) (ΔO)	0.57		0.33			

TABLE 2. Fruit yield for T1 (1460 L/tree), T2 (394 L/tree) and T3 obtained as the mean of 4 replicates per treatment and their standard error (SE). Equal letters between columns indicate that it was not significantly different between treatments according to the Duncan's test ($P \leq 0.05$).

		T1	S.E.	T2	S.E.	T3	S.E.
Yield (kg/tree)	I	14 a	3.28	10.7 a	1.43	10.7 a	1.43
	II	9.35 a	2.39	6.5 a	1.32	8.18 a	1.1
	III	0.28 a	0.11	0.63 a	0.19	0.63 a	0.21
	Total	23.59 a		17.86 a		19.5 a	
Fruit mean weight (g)	I	200 a	0	230 a	0.03	230 a	0.03
	II	180 a	0.03	180 a	0.03	200 a	0
	III	100 a	0	100 a	0	100 a	0
	Media	160 a		170 a		170 a	
Fruits/tree	I	61 a	14	46 a	7	45 a	6
	II	49 a	9.03	40 a	8.26	51 a	5.96
	III	3 a	1.11	6 a	1.66	6 a	2.12
	Total	113 a		92 a		102 a	

without significant differences according to Duncan's test ($P \leq 0.05$). More fruits were obtained per tree in T1 (113 fruits) than in T2 (92 fruits) and T3 (102 fruits). The highest number of fruits corresponded to categories I and II in all treatments, with no significant differences, meaning that the majority of the fruit corresponded to fruits larger than 50 mm coinciding with Pérez *et al*. (2014); De la Rosa *et al*. (2015), who did not find significant differences in peach yield under moderate RDI treatments.

Although there was no significant difference in yield, there is a slight variation of T1 considering that the water status of the tree (Ψ_t) did not show significant differences between T1 and T2. The results suggest that the T2 represents water saving up to 75% during the rapid fruit growth stage (obtaining similar yield results).

As the plant water relations did not present significant differences between treatments, there was no difference in the quality parameters: volume, density, sphericity, color index (CI) of pulp and peel, firmness and TSS according to Duncan's test ($P \leq 0.05$) (Tab. 3) similar to that found by De la Rosa *et al*. (2015) in nectarines, indicating that the fruits in the three treatments present similar quality characteristics.

The sphericity of the fruits was 0.96 which is very close to one (1) indicating an almost spherical shape typical of the Triumph of Vienna pears what may be a desired attribute of quality for consumers. The titratable total acidity (TTA) and maturity index (MI) were the only parameters with significant difference according to the Duncan's test ($P \leq 0.05$) between Control and T2 and T3. Because the MI is derived from the relation between TSS and TTA, its variation is due to the reduction of malic acid quantity for T1. Parra *et al*. (1998) reported mean TSS values similar to those found (12.67 °Brix) indicating that as the fruit grows and develops in the plant, °Brix increases, while the acid content decreases. The MI had values higher than those reported by Arenas (2012) for the same species under normal irrigation conditions and lower than those obtained by Abril (2015) (41, 48 y 46 °Brix gL^{-1} for T1, T2

TABLE 3. Fruit quality parameters for T1, T2 and T3 obtained as the mean of 4 replicates per treatment and their standard error (SE). Equal letters between columns indicate that it was not significantly different between treatments according to the Duncan's test ($P \leq 0.05$).

	T1	SE	T2	SE	T3	SE
Volume (cm^3)	186 a	13.212	178.38 a	8.831	173.38 a	10.72
Density (g cm^{-3})	1.07 a	0.037	1.03 a	0.038	1.15 a	0.075
Sphericity	0.96 a	0.008	0.96 a	0.006	0.96 a	0.008
CI of peel	-1.78 a	0.902	-1.05 a	0.698	-1.54 a	0.618
CI of pulp	-1.78 a	0.902	-1.05 a	0.698	-0.53 a	0.205
Poles firmness (N)	11.51 a	1.020	11.9 a	1.295	12.26 a	0.609
Ecuador firmness (N)	15.19 a	1.138	15.71 a	0.748	13.99 a	1.001
TSS (°Brix)	14.21 a	0.315	14.38 a	0.514	14.91 a	0.488
Titratable total acids (% malic acid)	0.33 a	0.021	0.43 b	0.037	0.48 b	0.024
Maturity index (°Brix gL^{-1})	44.1 a	2.744	34 b	3.157	30.76 b	2.079

y T3 respectively) and Molina (2014) (61, 65 y 61 °Brix gL^{-1} for T1, T2 y T3 respectively).

Conclusions

Pear trees were resistance to the water deficit as they performed osmotic adjustment, but osmotic potential was similar in all treatments. The application of RDI did not affect the yield or quality of the fruits in relation to the well irrigated trees, indicating that a similar production can be achieved with savings of water up to 100% during the rapid fruit growth stage.

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