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Comunicación breve

Soil loss as a result of the interactions between natural landscape attributes and human activities in Ventania, Argentina

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Abstract. The Ventania System is a hilly area emerging in the extended Pampas plains of Argentina. Shallow soils with rock fragments and steep slopes are the main limitations for agriculture in this area. The effect of land use changes on annual soil loss on these soils in the Belisario Creek watershed was estimated. The universal soil loss equation (USLE) was applied for 1966 and 2016 to estimate soil loss generated by water erosion at the watershed scale. The equation was fed with rainfall, soil, slope, land use and management local data. Critical areas were identified using a geographic information system. The watershed has increased its fragility. For instance, the ranges of high and very high risk of soil loss (>50 $Mg.ha^{-1}.y^{-1}$.) increased their coverage from 18% (1966) to 44% (2016). This increment was caused by land use transformations. This shows the urgent need to establish sustainable management strategies, especially considering livestock and demographic expansion. Similar methodological approaches might also be applied to analyse nearby watersheds, aiming to identify priority areas for designing future management strategies.

[Keywords: land use change, erosion, territorial management]

Resumen. La pérdida de suelo como resultado de las interacciones entre los atributos del paisaje natural y las actividades humanas en Ventania, Argentina. El Sistema de Ventania es un área serrana característica que emerge en la extensa llanura pampeana de Argentina. En esta región, las principales limitantes para la agricultura son los suelos someros con fragmentos de rocas y las pendientes pronunciadas. Estimamos el efecto del cambio del uso de la tierra sobre la pérdida anual de suelo en la cuenca serrana del arroyo Belisario. Se aplicó la ecuación universal de pérdida de suelo (USLE) para 1966 y 2016, a fin de estimar la pérdida de suelo por erosión hídrica. La ecuación se alimentó con datos de precipitación, suelo, pendiente, uso del suelo y prácticas de manejo. Las áreas críticas se identificaron por medio de un sistema de información geográfica. Se encontró un aumento en la fragilidad de la cuenca. Por ejemplo, los rangos de alto y muy alto riesgo de pérdida de suelo (>50 $Mg.ha^{-1}.año^{-1}$) pasaron de ocupar 18% de la cuenca (1966) al 44% (2016). Este incremento obedeció a las diferencias encontradas en el uso de la tierra. Se enfatiza la necesidad urgente de establecer estrategias de manejo sustentable dentro de la cuenca, con especial foco en la actividad ganadera y la expansión demográfica. El análisis de cuencas serranas cercanas empleando metodologías similares permitiría identificar áreas prioritarias y diseñar futuras estrategias de manejo.

[Palabras clave: cambio de uso del suelo, erosión, ordenamiento territorial]

Introduction

Soil erosion involves sediment detachment from soil surface, both by raindrop impact and flowing water (Jain and Kothyari 2000). Erosion results in degradation of soil productivity in many ways, such as the decrease of plants' rooting depth (O'Geen and Schwankl 2006). Interactions between land use, erosion and sediment yield can be quite complex, particularly in areas with changing land use and agricultural practices (Tramblay et al. 2010). In addition to rainfall, runoff and erosion processes are strongly affected by many factors (Fang et al. 2013). For example, land use changes might strongly impact on erosion rates, also increasing sensitivity of landscapes to disturbance and, therefore, making them more vulnerable to extreme events (Boardman 2006). In addition to geological erosion, a faster and more detrimental erosion process might be induced by human practices such as forest clearing, raising crops and domesticated animals, mining and construction (El-Swafy et al. 1982).

Soil erosion causes soil loss and reduces soil depth, reducing soil water storage capacity and, thus, crop yields (Li et al. 2009). Continued soil loss will become a critical problem for global agricultural production under conventional upland farming practices

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(Montgomery 2007). The mechanism by which erosion affects soil productivity under different farming conditions should be understood for the development of effective soil management strategies (Li et al. 2013). Among the available soil erosion and sediment yield models, the universal soil loss equation (USLE) and its modified and revised versions are some of the most commonly used models (Sadeghi 2004). The guidance on generating methodological decisions in conservation planning, by predicting the average rate of soil erosion on a particular site, is a major purpose of the USLE (USDA 1997). In this field, the analysis of remote sensing data together with spatial information in a GIS environment further points to an integrated approach (Ali and Hagos 2016).

The aim of this work was to estimate the effect of land use changes on annual soil loss on a hilly watershed located in the Ventania System. Although scientific information related to soil and water resources at regional scale is available, it is quite scarce at a watershed scale. This work might help provide useful information for territorial planning and management strategies in an area with growing demographic and tourism activity.

Materials and Methods

Soil loss estimations were done for years 1966 and 2016 in order to compare results from two different land use scenarios, spaced out by fifty years. Year selection was based on data availability (aerial photographies for 1966 and satellite imagines and field campaigns for 2016), and also in order to consider two dissimilar circumstances. Geospatial data analysis was done within the open source geographic information system QGIS 2.18, downloaded from https://www.qgis.org/en/site/forusers/download.html. Scale was 1: 50000 and pixel size was 30 m.

Study area

In Argentina, the Buenos Aires province has the highest demographic and industrial concentration, and also the largest agriculture and livestock production. The Tandilia and the Ventania Systems are the only hilly areas emerging in this province. At regional scale, tourism is an emerging activity, based on landscape and natural resources. Land use includes cattle grazing on native and improved pastures, and cultivation of wheat, oats, sunflower, sorghum, and soybean. The region presents a semiarid temperate climate (Fernández et al. 2009), with a mean annual precipitation of 855 mm, for the period 1980-2006 (Delgado 2014). The Ventania System belongs to the Southern District of the Pampas Phytogeographic Region. Grass steppe is the dominant vegetation, and *Stipa*, *Piptochaetium*, *Festuca* and *Briza* are among the most common grass genera (Zalba et al. 2008). There are two major types of plant communities: short-needlegrass on poor soils and tall-tussock grasslands on rich soils (Loydi et al. 2010).

The watershed of the Belisario Creek is located in the Ventania System, at 38°04′ S and 61°55′ W (Figure 1), with a total area of 2596 ha (Delgado 2012) and marked hilly topography (altitudes between 350 and 1100 m a.s.l.). The Belisario Creek is tributary of "El Oro" Creek, which flows into the "Sauce Grande" River. This is the main river in the Southwest Pampas (Quattrocchio et al. 2008), and the main water source of the "Paso de Las Piedras" dam that supplies water to the cities of Bahía Blanca and Punta Alta (Marucci et al. 2011).

The upper watershed has steep slopes and predominance of lytic Hapludolls; middle and lower watershed have primarily typic Hapludolls. Their main characteristics are the scarce soil depth and the presence of fragmented rock and tuff, associated with steep slopes. Land use types include natural grassland, with presence of rocks on the upper watershed. Degraded natural grassland predominates on the medium and lower part of the watershed, caused by the constant presence of livestock through many years. Also, there are agriculture activities and planted forests in small areas. The tourist village of Villa Ventana is placed in the lower part of the watershed, with an established population of 1000 inhabitants. This village has sparse houses, unpaved streets and is surrounded by a particular urban forest, developed before permanent population was established. It is mostly composed of exotic species: conifers (mainly pines and cypress), some elms and acacias. This area is under a mayor process of tourist and population expansion, accounting for additional demand on services and resources (Delgado et al. 2015).

Soil loss estimation

The universal soil loss equation (USLE) was used to estimate spatial distribution of soil

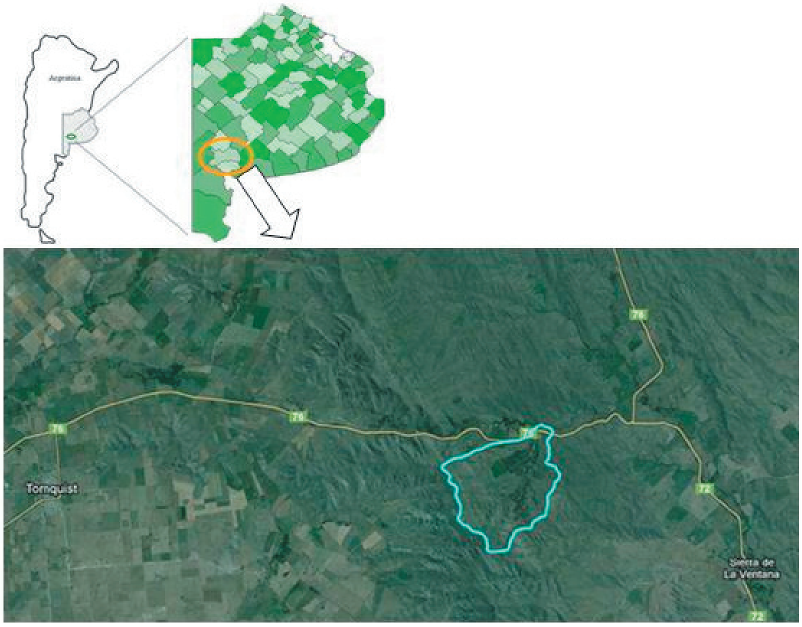

Figure 1. Case study area. Watershed of the Belisario Creek, Southwest of Buenos Aires province, Argentina. On a Google Earth® image.

Figura 1. Área de estudio. Cuenca del Arroyo Belisario, sudoeste de la provincia de Buenos Aires, Argentina. Sobre una imagen de Google Earth.

loss. Wischmeier and Smith (1978) proposed it to calculate soil erosion rates, based on data concerning to rainfall, soil, slope, land use and soil conservation practices (Equation 1). Since it is a multiplicative operation, the bigger each factor, the bigger the result from the whole equation, and so, the estimated soil loss.

$$A = R * K * LS * C * P \qquad \text{Equation 1}$$

where A=average soil loss per unit of area (Mg.ha^{-1}.y^{-1}), R=rainfall-runoff erosivity factor, K=soil erodibility factor; LS=topographic factor, C=cover management factor, P=support practice factor. The five factors were established according to Wischmeier and Smith (1978) and are briefly described below.

<u>Rainfall-runoff erosivity factor (R)</u>. It considers the rainfall energy to generate erosion. It is a function of the total energy of the rainfall event and the rainfall maximum intensity in 30 minutes. Due to the scarcity in extended pluviograph registers for this area, the R factor was established based on published data by Rojas and Conde (1985). Available data refers to pluviometer registers (daily data), which makes it impossible to calculate new and specific R factor for this watershed.

<u>Soil erodibility factor (K)</u>. It represents an integrated average value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes. Necessary data for its estimation was obtained from the Soil Cartographic Units (SCU) description of the National Institute for Agricultural Technology, scale 1:50000 (INTA 1987).

<u>Topographic factor (LS)</u>. It includes the slope length factor (L) and the slope steepness factor (S). The LS factor was calculated using the topographic sheet No. 3963-6-1 (IGM 1979), scale 1:50000. Contour lines were digitalized, rasterized and interpolated in order to generate the digital terrain model (DTM). Then, the generated slope map (%) was used to estimate the LS factor at a pixel scale.

<u>Cover and management factor (C)</u>. This factor measures the combined effect of all the interrelated cover and management variables. C factor was determined for year 1966, based on aerial photographies and information gathered from interviews to local people and authorities; for year 2016, it was defined through field observation and satellite images obtained from Google Earth©.

<u>Support practice factor (P)</u>. As mentioned by Devatha et al. (2015), this factor is an expression of the effect of specific conservation practices (i.e., contouring, strip cropping, terracing and subsurface drainage) on soil. These practices affect erosion by modifying the flow pattern, direction, amount and rate of runoff.

The five factors involved in the USLE equation were multiplied with each other in order to obtain annual soil loss for years 1966 and 2016. Soil loss (Mg.ha^{-1}.y^{-1}) was classified into 4 ranges of risk, based on FAO (1980): low (<10), moderate (10-50), high (50-200) and very high (>200). Differences between years 1966 and 2016 were based on changes applied on the C and P factors. No modifications were done to the other three factors of the equation. Limitations for R factor were already explained; the same happens for K factor, where only one official data available (INTA 1987). Concerning topography, it was considered that LS did not changed over time.

The Guide for Soil Loss Tolerance (López Cadenas de Llano 1998) was used to identify differences between soil loss tolerance and soil loss estimated by USLE. This methodology considers root system and soil characteristics. Soil loss tolerance denotes the maximum rate of soil erosion that can occur and still allow crop productivity to be economically sustained. It considers the loss of productivity due to erosion and the rate of soil formation from parent material, the rate of top soil formation and the loss of nutrients (USDA 1997).

Results

Due to the lack of official data that could enable to calculate a new R factor, the value 289 $J.cm.m^{-2}.h^{-1}$ obtained from bibliography was considered homogeneous throughout the entire watershed. Concerning K factor, the two identified SCU were Duf 2 and R. The first one presented a loam fine texture, medium runoff, moderate permeability and tuff at 80 cm below ground. SCU R was located on hilly areas with high presence of rock outcrops and poor conditions for agronomic activities.

The estimated K factors ($Mg.m^{2}.h.ha^{-1}.J^{-1}$), were 0.53 (856 ha) and 0.95 (1740 ha), respectively. LS factor was considered quite complex, so, for further analyses it was distributed in three ranges: <3 (1757 ha), between 3 and 9 (765 ha) and >9 (74 ha). Regarding C factor, most relevant changes were the conversion of conventional agriculture areas (142 ha) to agriculture with conservation practices (contouring), transformation of most of the area covered with exotic trees (290 ha) into the current semi-urban area of Villa Ventana (227 ha) and also the emergence of degraded grassland areas (763 ha) due to overgrazing (explained by land use conversion of part of the natural grassland in good condition to degraded grassland). The riparian vegetation has not presented changes related to its area of distribution. Table 1 shows C factor assigned to each land use. The P factor value was established as 1 for the whole watershed for year 1966 (based on the lack of conservation measures). For year 2016, its value decreased to 0.6 in areas occupied by crops with contour lines, representing 5.5% of the watershed (141.8 ha).

Soil loss

Figure 2 shows soil erosion classified into four classes according to FAO. Regarding soil loss tolerance, 78% of the watershed showed 2.2 $Mg.ha^{-1}.y^{-1}$ of tolerance to soil loss, associated to degraded grassland and natural grassland with shallow rocks. The rest of the watershed presented 14% of the area, with 6.7 $Mg.ha^{-1}.y^{-1}$ of tolerance to soil loss and 8% with 4.5 $Mg.ha^{-1}.y^{-1}$. Table 2 shows ranges of

Table 1. Cover management factor (C factor) assigned for year 1966 and 2016, in the watershed of the Belisario's Creek.

Table 1. Factor de cobertura y uso del suelo (factor C) asignado para los años 1966 y 2016, en la cuenca del Arroyo Belisario.

Land use	1966	2016
Natural grassland in good condition	0.011	0.011
Riparian vegetation	0.038	0.012
Forest	0.08	0.03
Semi-urban area	0.08	0.09
Natural grassland with shallow rocks	0.04	0.11
Degraded grassland	0.067	0.13
Crops	0.25	0.25
Vineyard	-	0.4

According to experimental C factors, published by Wischmeier and Smith (1978)

Table 2. Ranges of differences between soil loss tolerance ($Mg.ha^{-1}.y^{-1}$) and soil loss ($Mg.ha^{-1}.y^{-1}$).

Tabla 2. Rangos de diferencias entre la pérdida de suelo ($Mg.ha^{-1}.y^{-1}$) y la tolerancia a la pérdida de suelo ($Mg.ha^{-1}.y^{-1}$).

Ranges of difference ($Mg.ha^{-1}.y^{-1}$)	Characteristics
<0	This range encompasses areas where tolerance is larger than soil loss estimated by USLE. It is mostly coincident with forest and semi-urban land uses, including also natural grassland in good conditions. This range occupied 509 ha in 1966 and 432 ha in 2016.
0-10	This range shows a moderated risk and is mostly present in the middle and lower watershed. It occupied 670 ha in 1966 and 482 ha in 2016.
>10	This range represents a high risk and it mainly occupies the middle and upper. This area needs urgent implementation of conservation measures. It occupied 1417 ha in 1966 and 1682 ha in 2016.

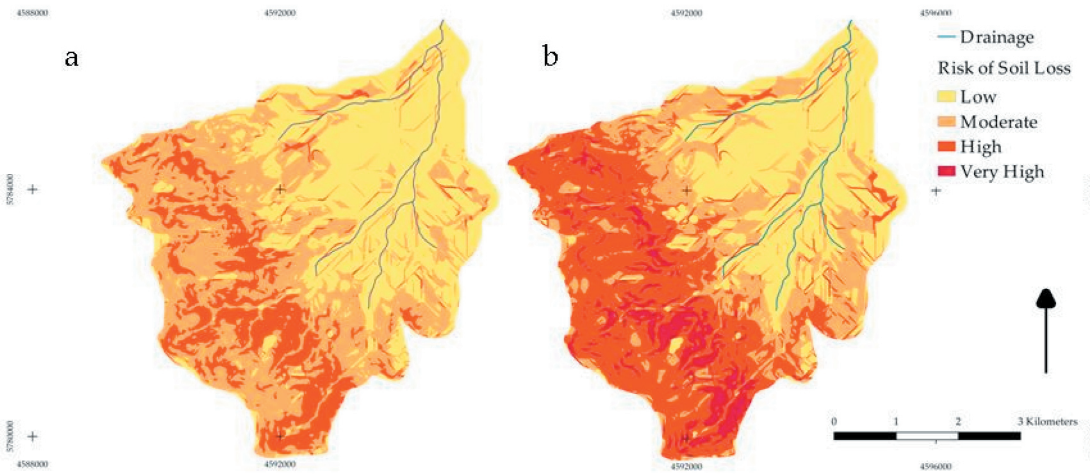

Figure 2. Soil loss (Mg.ha^{-1}.y^{-1}) according to FAO classification (1980). a) year 1966; b) year 2016. Low: <10; moderate: 10-50; high: 50-200; very high: >200.

Figura 2. Pérdida de suelo (Mg.ha^{-1}.año^{-1}) según la clasificación de FAO (1980). a) Año 1966; b) Año 2016. Bajo: <10; moderado: 10-50; alto: 50-200; muy alto: >200

differences between soil loss tolerance and soil loss, for years 1966 and 2016.

Discussion

Based on the spatially distributed characteristics of soil loss process (Pandey et al. 2007), the application of the USLE equation in a GIS environment allowed to analyse soil erosion with high detail. The model was applied to identify critical areas where land use should be controlled in order to avoid present and future damages. Unfortunately, estimated soil loss had increased considerably over time (Figure 3). A current high grade of fragility in the watershed is here reported. For instance, the low and moderate ranges of soil loss decreased from over 80% (1966) to only 56% (2016). On the other hand, the areas with high and very high risk increased their occupancy from 18% (1966) to 44% of the watershed (2016).

Regarding soil loss tolerance, the high level of fragility in the watershed is also evident, with a large increment in the area corresponding to differences between soil loss and soil loss tolerance greater than 10 Mg.ha^{-1}.y^{-1} (this range mainly occupies the middle and upper watershed). At the same time, the other two ranges of differences decreased: the range 0-10 Mg.ha^{-1}.y^{-1} is mostly in the middle and lower watershed, and the range <0 Mg. ha^{-1}.y^{-1} is predominantly placed in the lower watershed, and coincident with forest, semi-urban and natural grassland in good conditions land uses.

In relation to afforestation already established on 1966, its dynamic was modified due to

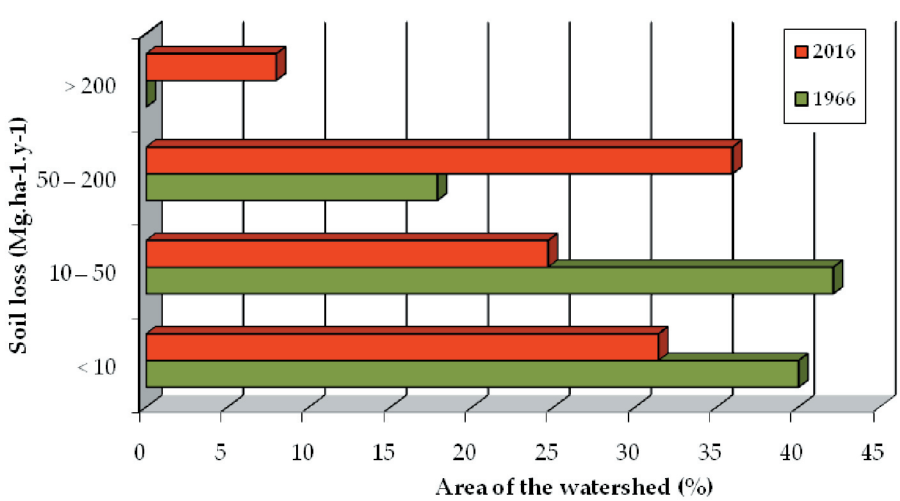

Figure 3. Area of the watershed (%) occupied by each range of soil loss (Mg.ha^{-1}.y^{-1}) according to FAO classification (1980). Years 1966 and 2016.

Figura 3. Área ocupada de la cuenca (%) por cada rango de pérdida de suelo (Mg.ha^{-1}.año^{-1}) según la clasificación de FAO (1980). Años 1966 y 2016.

the recent urbanization of Villa Ventana (this village was founded in 1947, but remained covered by exotic trees and mostly uninhabited for many decades, reason why the C factor assigned in 1966 was similar to the one assigned to forest). Comparison of current land use to that one going on 50 years before shows the urgent need to establish sustainable management strategies. In particular, the semi-urban area of Villa Ventana adds complexity to the analysis. This village has a major touristic and recreational use due to its scenic beauty and relaxing atmosphere. This growth of tourism activities and the increment in urban development is also taking place in others semi urban towns around the Ventania System. According to Pappas et al. (2008), urbanization processes tend to increase runoff volume and peak flow with the corresponding increment in erosion and flooding extent and frequency. On the other hand, forested areas not affected by the urbanization process showed a C factor decline (due to forest growth). C factor also diminished for the riparian area, based on growth of the vegetative cover mostly represented by the exotic deciduous shrub Spanish broom (*Spartium junceum*).

Considering that morphometry strongly influences the watershed response, it is expected that geologic erosion occurs in this hilly area. Also, edaphic characteristics and the scarce vegetation naturally increase susceptibility to erosive process. Soils of the lower watershed are appropriated for agriculture activities; differently, the upper watershed has shallower soils and steeper slopes (Delgado 2010), increasing runoff and transport of suspended material. In relation to sediment yield, Delgado (2012) determined total suspended solids (TSS) at the sink of the watershed (flow rate of 1.87 m^3/s and a drainage area of 2596 ha), with a peak of 141 mg/L (264.2 g/s). Besides this study, there is no other field available data regarding sediment yield in the watershed of Belisario Creek.

Soil erosion risk could represent a useful indicator for policymakers and planners to prioritize soil conservation. Yang et al. (2012) showed that the sensitivity of soil erosion to climate changes may be higher with less favourable landscape pattern, considering the importance of carrying out conservation measures such as afforestation. In this particular area, afforestation might be considered an alternative in order to control soil erosion. However, this criterion will require further evaluation, in agreement with prior reports (Zalba et al. 2008) that considered pines as potential invaders in the Pampas grassland ecosystems. On one hand, this invasive behaviour can be easily observed nowadays in many hills of the Ventania System, where trees (mainly pine trees) are spreading over natural grassland. On the other hand, this will require additional research on the influence of forest cover on the hydrologic cycle; many authors mention that forest's main effect is caused by the amount of rainfall retained by canopy and that is no longer available for water balance (Feller 1981; Calder 1998; Putuhena and Cordery 2000; Huber and Iroumé 2001).

Considering data scarcity for this area, the USLE was appropriate in order to obtain an approximate estimation of soil loss on the watershed. The simplicity of the model makes it useful to reach a preliminary approach. But, since data scale used in this research was 1: 50000, more detailed studies should be done in order to evaluate specific soil loss in specific areas of the watershed. Similar methodological approaches might also be applied to analyse nearby watersheds aiming to help contribute to the design of future territorial management strategies for this fragile territory. According to Podmanicky et al. (2011), erosion strongly impacts soil productivity; thus, these predictions have environmental but also socio-economic implications. Present analysis might be used by decision makers to support policies in order to reduce soil erosion and ensure the sustainable management of the area, helping to avoid further damages to the environment as well as the people living in this territory. This kind of spatial-temporal analysis represents a comprehensible and easy way to show the problematic to people not closely related to the science field, considering not only decision makers, but also local people, which represent one of the most important actors for a reliable and long-lasting territorial management.

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