

THE RAINFALL USE EFFICIENCY AND SOYBEAN GRAIN YIELD UNDER RAINFED CONDITIONS IN VOJVODINA

Violeta Mandić¹, Zorica Bijelić¹, Vesna Krnjaja¹, Aleksandar Simić²,
Dragana Ružić Muslić¹, Vesna Dragičević³, Veselin Petričević¹

¹Institute for Animal Husbandry, Autoput 16, 11080 Zemun, Republic of Serbia

²University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Zemun, Republic of Serbia

³Maize Research Institute “Zemun Polje”, Slobodana Bajića 1, 11185 Belgrade

Corresponding author: violeta_randjelovic@yahoo.com

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Abstract: Rainfall is one of the most important environmental factors influencing crop production under dry land farming conditions. In the Republic of Serbia, the soybean is produced under rainfed conditions, and therefore online monitoring of the rainfall use efficiency (RUE) is essential for efficient management of production. The research aim was to estimate the effects of amount rainfall during the growing season (RGS) and average monthly rainfall on soybean grain yield (GY) in the Vojvodina during the sixteen year period (2000-2015). Distributions of RGS were not satisfactory and negatively influenced the expression genetic yield potential of cultivars. Rainfall deficits during the growing season limited the soybean plant reproductive growth stages leading to GY loss. The coefficient of variation indicated that RGS and monthly rainfall changed moderately from year to year. Regression equations showed that GY tended to increase with the amount of rainfall. GY had strong positive relationship with RGS and rainfall in May, July and August. Since the amount and distribution of rainfall during growing season are critical determinants of GY, soybean cultivars of shorter vegetation periods should be developed and cultivated so that maximum utilization of rainfall is ensured.

Key words: correlation, regression, grain yield, rainfall, soybean, Vojvodina

Introduction

Soybean is very important legume crop used for livestock and human nutrition and industrial processing. Soybean grain is source of edible oil (grain contains about 20% oil) and largest source of high quality protein for animal feed

(grain contains about 40% protein). Generally, the high production of soybean grain is important strategy for stable and profitable livestock production. It is estimated that 47% of soybean grain produced in the US is used for animal feed and that 98% soybean meal as a byproduct in processing is used to feed cows, pigs and chickens (*Soyatech, 2017*). In Serbia, soybean is a source of protein for livestock, poultry and fish (*Popović et al., 2015*), commonly contained in cereals mixtures for farm ruminant and non/ruminants nutrition (*Randjelović, 2009*). It takes one kilogram of soybean flour to produce 2.3 kg of meat and 12 l of milk (*Todorović and Kondić, 1993*). In Serbia, grain yield of soybean is dependent on RGS (amount and distribution of rainfall during the growing season) because production is exclusively organized under dry land farming conditions. Information on the amount and distribution of rainfall are very important strategy for soybean productivity, because it is estimated that extreme weather conditions (drought and heat wave) will become even more intensive in the future (*Lalić et al., 2011*). Generally, in Serbia variation of rainfall regime is typical during summer seasons (*Mandić et al., 2015a, 2017*). The critical stages for water requirement for soybean are from the beginning of flowering until the end of grain filling when the main yield components are formed. *Bošnjak (2004)* and *Mandić et al. (2015a)* concluded that in Serbia GY of soybeans depends on the amount of rainfall from June to September when soybeans plants are in flowering and pod-filling growth stages. *Randjelović et al. (2010)* and *Mandić et al. (2015b)* reported that GY especially depends on the amount of rainfall in August when soybean plants are in the grain filling stage. Water deficit in flowering stage may enhance the flower abscission (*Hoque et al., 2015*), while drought during seed filling caused soybean plants to produce smaller seeds, influencing total yield (*Dornbos and Mullen, 1991*). According to *Fageria et al. (2010)*, soybean can be cultivated between 0° to 55° latitude and to 2000 m altitude. Therefore, Vojvodina district is very suitable for soybean production because of its favorable geographic location, climate and natural characteristics. However, amount and distribution of rainfall are limiting factors for soybean development. *Nenadić et al. (1995)* state that soybean can achieve a satisfactory GY if the level of precipitation during June, July and August is about 300-350 mm.

The aim of this investigation was to estimate the effects of amount of rainfall during the growing season (RGS) and monthly rainfall (MR) on soybean GY in Vojvodina during sixteen years (2000-2015) and to evaluate the degree of association between monthly rainfall variation and grain yield.

Materials and Methods

Vojvodina is located in the north of Serbia (Latitude 45° 0' 0 N; Longitude 20° 0' 0 E). Rainfall data (2000-2015) were retrieved from Meteorological

yearbooks (*Republic Hydrometeorological Service of Serbia*) including seven meteorological stations which have data of monthly rainfall (Table 1). Selected rainfall stations are equally distributed on the region Vojvodina (one station per 3000 km²). The elevations of the meteorological stations range from 80 m a.s.l. to 102 m a.s.l.

Table 1. List of meteorological stations included in the study

Station	Latitude	Longitude	Altitude (m)
Vršac	45°08'N	21°18'E	84
Zrenjanin	45°22'N	20°25'E	80
Kikinda	45°51'N	20°28'E	81
Palić	46°06'N	19°46'E	102
Rimski Šančevi – Novi Sad	45°20'N	19°51'E	84
Sombor	45°46'N	19°09'E	88
Sremska Mitrovica	45°06'N	19°33'E	82

Data for soybean GY for Vojvodina were extracted from the Statistical Yearbook of the Republic of Serbia from 2000 to 2015.

Descriptive statistics (mean (M), coefficients of variation (CV), maximum and minimum values) were used to summarize data. The formula according to *Oweis (1997)* was used for estimate rainfall use efficiency (RUE): $RUE (kg ha^{-1} mm^{-1}) = \text{grain yield} / \text{rainfall received during the growing season}$. The programs 'Excel' and STATISTICA (version 10; StatSoft, Tulsa, Oklahoma, USA) were used in the analysis of data, while the Shapiro-Wilk test was used to assess data normality. The linear regression method and correlation analysis were used for analysis of data at the level of significance $P \leq 0.05$ and $P \leq 0.01$. The Pearson's correlation coefficient was used for determining the strength of the linear relationship.

Results and Discussion

Results showed that RGS, in average for all meteorological stations and years, was 364.5 mm and ranged from 117.4 mm (Kikinda) to 757.0 (Vršac), Table 2. In general, the rainfall data for Vojvodina showed irregular temporal and spatial distribution of rainfall. Earlier studies showed that Vojvodina district received 305 mm of rainfall from April to August during sixteen years (*Mandić et al. 2017*), and 303.5 mm during sixty five years (*Milošević et al. 2015*). RGS varied from 38.7% in Sremska Mitrovica to 43.8% in Rimski Šančevi, with an average value of 41.7%. It means that the RGS is moderately variable. Monthly rainfall during June was the highest (76.6 mm) and contributed 21.02% of RGS (364.5 mm), followed by May (19.29%), July (16.38%), September (16.32%), August (14.73%) and April (12.26%). The CV was the highest in August (82.0%), followed by April (78.3%), June (71.4%), September (68.2%), July (67.9%) and May (59.5%). In Vojvodina

rainfall variability is important for explaining soybean yield variability, because soybean is not irrigated. Also, *Ray et al. (2015)* point out the importance of rainfall variability for soybean grain yield in northeastern China. These authors concluded that 36% of the GY variability was explained by rainfall variability. Vojvodina district received the highest amount of rainfall during growing season in June when soybean plants were at the stage of flowering and the formation of the first pods started. Vojvodina region received the lowest amount of rainfall in April, which is the optimal time for sowing of soybean. The high CV recorded in August and April were an indication of lowly dependable rainfall. Also, the CV in other months confirmed the moderate variability of the average monthly rainfall, and generally monthly rainfall are lowly dependable.

Table 2. Descriptive statistics of the rainfall growing seasons (RGS) and monthly rainfall for seven meteorological stations in Vojvodina (mm)

Station	Item	IV	V	VI	VII	VIII	IX	RGS
Vršac	M	52.7	62.2	76.5	76.1	63.7	58.7	389.9
	CV, %	68.4	43.5	66.4	98.0	88.0	79.8	43.0
	Maximum	130.4	120.1	202.9	275.0	184.6	193.4	757.0
	Minimum	1.0	15.2	14.2	0.6	0.4	2.2	193.6
Zrenjanin	M	39.2	60.2	74.0	52.7	48.4	63.4	337.9
	CV, %	71.7	70.5	47.5	72.4	101.8	72.6	41.4
	Maximum	97	162.1	139.6	153.5	155.1	185.3	615.6
	Minimum	2.5	19	32.3	12.5	0.6	10.2	144.4
Kikinda	M	43.6	62.0	68.1	58.7	45.4	55.6	333.4
	CV, %	88.5	70.9	79.8	54.0	71.9	57.9	43.0
	Maximum	121.2	184.2	202.6	115.3	129.8	121.8	683.7
	Minimum	1.3	14	9.4	13.5	3.9	4.6	117.4
Palić	M	42.5	72.3	77.8	57.7	52.2	56.8	359.3
	CV, %	81.3	51.5	80.5	58.1	68.1	63.5	39.2
	Maximum	132.3	158.9	243.3	115.1	135.1	137.4	584.2
	Minimum	2.7	14.1	8	3.7	2.6	7.6	128.1
Rimski Šančevi	M	46.0	84.9	87.9	59.4	56.8	61.5	396.4
	CV, %	93.5	60.8	71.2	61.1	91.1	65.3	43.8
	Maximum	156.0	202.1	237.4	141.1	168.5	160.1	742.0
	Minimum	0.0	21.9	26.7	2.6	1.5	13.1	148.1
Sombor	M	42.0	75.4	78.6	62.5	55.7	61.5	375.7
	CV, %	75.7	66.8	86.1	70.8	70.1	65.3	42.5
	Maximum	109.0	195.4	240.0	195.5	154.7	138.7	694.0
	Minimum	0.5	13.0	9.8	18.3	5.5	15.0	138.3
Sremska Mitrovica	M	46.7	75.3	73.6	50.8	53.8	59.0	359.2
	CV, %	70.1	53.5	67.9	49.4	81.6	72.1	38.7
	Maximum	109.8	187.0	220.4	93.5	156.2	154.9	632.2
	Minimum	0.0	28.3	20.8	10.4	0.1	5.8	135.2
M	M	44.7	70.3	76.6	59.7	53.7	59.5	364.5
	CV, %	78.3	59.5	71.4	67.9	82.0	68.2	41.7
	Maximum	156	202.1	243.3	275	184.6	193.4	757
	Minimum	0	13	8	0.6	0.1	2.2	117.4
% Contribution to RGS		12.26	19.29	21.02	16.38	14.73	16.32	100

In Serbia, soybean needs 450-480 mm of RGS for grain production, by months - in April 10 to 40 mm, May 30 to 60 mm, June 90-110 mm, July 100 to 125 mm, August 100 to 120 mm and September 50 to 80 mm (*Glamočlija, 2004*). The most water is needed from the beginning of flowering until the end of grain filling, which is time from late June to early September (*Srebrić and Perić, 2014*), depending on the group of maturity. *Glamočlija (2004)* concludes that in order to achieve high and stable grain yield and above-ground biomass, there should be 250-300 mm of rainfalls during summer months (June-August). In the 3-month period June-August for the period of observed sixteen years, Vojvodina received an average rainfall of 190mm (76.6 mm in June, 59.7 mm in July and 53.7 mm in August) which is lower than maximum water consumption for this period.

During the 16-year period, enough rainfalls for successful soybean production were registered in 2001, 2005, 2010 and 2014 (Table 3). Generally, RGS values in investigated period were lower than optimal amount of rainfall for soybean production. CV of monthly rainfall for all years of research ranged from 56.5% (July) to 72.5% (August), while for RGS it was (39.1%). Increased rainfall variability indicates greater seasonal fluctuations of rainfall in Vojvodina district. Likewise, increased CV indicates that the rainfall is highly variable and less predictable. This amount seems to be sufficient to cultivate of soybean. Given that the established RGS have wide variations in Vojvodina, and that production of soybeans and all crops on arable land depends on rainfall, and minor adaptation strategies, it is realistic to expect a large loss of yield in future. Therefore, the breeders must create drought and heat tolerant genotypes, and farmers should cultivate these cultivars.

Difference between maximum and minimum of rainfall within a month represents monthly range of rainfall. The increase in the monthly range of rainfall is associated with larger maximum of rainfall and smaller minimum of rainfall. Monthly range of rainfall ranged from 100.6 mm (April) to 178 mm (June). Generally, the long-term average monthly rainfall in Vojvodina district shows that most of the months were below average rainfall for soybean growth, with the exception of 2001, 2005, 2010 and 2014.

Table 3. Descriptive statistics for monthly rainfall from 2000 to 2016 (mm), grain yield – GY (t ha⁻¹) and rainfall use efficiency – RUE (kg ha⁻¹ mm⁻¹)

Year	IV	V	VI	VII	VIII	IX	RGS	GY	RUE
2000	33.0	30.8	22.3	25.7	4.7	27.2	143.6	1.2	8.4
2001	102.8	52.8	200.5	43.5	35.7	154.5	589.8	2.4	4.1
2002	26.5	63.4	46.3	48.2	51.3	48.7	284.4	2.5	8.8
2003	16.0	27.4	30.5	68.7	24.0	68.1	234.6	1.7	7.2
2004	93.5	72.6	73.9	80.8	57.4	45.5	423.6	2.7	6.4
2005	68.2	49.4	91.1	118.4	140.7	62.5	530.3	2.8	5.3
2006	86.3	51.7	91.7	44.7	107.6	17.4	399.5	2.8	7
2007	2.2	94.9	77.0	30.6	57.3	71.2	333.3	2.1	6.3
2008	37.2	33.8	95.1	50.5	27.7	71.7	315.9	2.5	7.9
2009	7.4	49.8	114.5	46.0	44.2	15.0	276.9	2.4	8.7
2010	50.5	142.9	162.2	67.6	104.4	77.7	605.2	3.2	5.3
2011	15.8	54.3	49.7	90.6	10.1	26.9	247.5	2.7	10.9
2012	62.2	59.9	30.7	61.4	3.3	23.5	241.1	1.7	7.1
2013	35.3	103.2	65.9	27.8	44.2	69.2	345.7	2.4	6.9
2014	57.9	149.5	46.3	137.1	71.1	114.1	576.0	3.6	6.3
2015	20.0	88.9	28.6	13.4	75.6	58.7	285.1	2.5	8.8
M	44.7	70.3	76.6	59.7	53.7	59.5	364.5	2.5	7.2
CV	69.9	52.2	64.9	56.5	72.5	61.8	39.1	23.8	23.4
Maximum	102.8	149.5	200.5	137.1	140.7	154.5	605.2	3.6	10.9
Minimum	2.2	27.4	22.3	13.4	3.3	15.0	143.6	1.2	4.1
Range	100.6	122.1	178.2	123.7	137.4	139.5	461.6	2.4	6.8

Legend: RGS - amount of rainfall during the growing season (mm); CV - coefficient of variation (%)

Average GY of soybean over longer period was 2.5 t ha⁻¹ and ranged from 1.2 t ha⁻¹ (2000) to 3.6 t ha⁻¹ (2014). The year 2000 had the lowest RGS and GY. It was a year when the rainfall in the summer months was the lowest (22.3, 25.7 and 4.7 mm). The genetic potential of soybean genotypes grown in Serbia is up to 6 t ha⁻¹, but rarely 50% is achieved. Unstable soybean yields in Serbia are the result of insufficient amount and irregular distribution of rainfall during the growing season. Introduction of irrigation would enable high and stable yields of soybean in variable climate conditions. However, in Serbia only 1% of arable land is irrigated (*World Bank, 2014*).

The CV of the GY in Vojvodina was 23.8%. This shows that there is no continuous high and stable production of soybean grain per unit area. That may be important as the limiting factor for production of milk, meat and eggs on farms. It should be noted that the CV of GY could be result of the joint effect of the rainfall variability, other climatic factors and non-climatic factors such as soybean cultivars and cropping technologies. It should be noted that the CV of GY could be result of the joint effect of the rainfall variability, other climatic factors and non-climatic factors such as cultivars and cropping technologies. The higher annual variability of soybean GY (39%) is reported by *Milošević et al. (2015)* during the period from 1949 to 2013.

In general, RUE tends to increase when aridity decreases indicating better rainfall utilization. Thus, higher RUE ($8.4 \text{ kg ha}^{-1} \text{ mm}^{-1}$) was found when rainfall was lowest (143.6 mm) compared to RUE ($5.3 \text{ kg ha}^{-1} \text{ mm}^{-1}$) when rainfall was highest (605.2 mm). Here it is assumed that the other conditions are equal.

Regression equations indicate that GY increased with increasing amounts of rainfall (Figure 1). Regression equations shows that for an increase of 1 mm of rainfall in April, May, June, July, August, September and the growing seasons the expected increase grain yield is 5.6, 10.3, 4.3, 9.8, 9.6, 5.2 and 3,1 kg ha^{-1} , respectively. Therefore, the highest increase of GY was could be attributed to the amount of rainfalls in May, July and August. *Dolijanović et al. (2013)* have found that 1 mm of annual rainfall increases the soybean GY from 2.1 to 2.9 kg ha^{-1} . The regression coefficient of determination for April was 9.1%, May 42.1%, June 13.3%, July 32.5%, August 41.5%, September 10.7% and RGS 57.2%, respectively. These percentages explained the variation in GY by rainfall variability. On the other hand, 42.8%, 91.9%, 57.9%, 86.7%, 67.5%, 58.5% and 89.3%, respectively, explained the variation in GY by other genetic and non-genetic factors (technical, other climatic, edaphic and biotic). As said, the highest rainfall in Vojvodina was in June (76.6 mm), but 1 mm of rainfall in June increased GY by only 4.3 kg ha^{-1} . Contrary, 1 mm of rainfall in May increased GY by 10.3 kg ha^{-1} . In May in Vojvodina, soybean plants form new leaves, expand more leaf area and create the optimal sizes of assimilation surfaces. Generally, the water stress reduced stem and leaf cell expansion, why the plants have short stems with less leaf area. Water stress in this period decreases leaf area even for 40% (*Catuchi et al., 2011*) and reduces photosynthetic rates and grain yield (*Neumaier et al., 2000*). Therefore, a greater development of leaf surface can increase the soybean yield. Rainfalls in July and August contributed to a higher yield increase. In Vojvodina (Serbia), in July and August soybean plants are at the stage of flowering and pods formation. Insufficient rainfall decreases the plant height. Also the plants are with a smaller number of pods, grains per pod, and the grain is small. Rainfall deficit and high temperatures influence the shortening of the vegetation period, so the grain filling stage is shortened. Thus, *Manavalan et al. (2009)* reported that water stress shortened the beginning maturity stage (R7) for 7 days, reducing yields for 44%.

A statistically significant positive correlation was found between GY and total rainfall in May ($r = 0.65$, $p \leq 0.01$), GY and total rainfall in July ($r = 0.57$, $p \leq 0.05$), GY and total rainfall in August ($r = 0.64$, $p \leq 0.01$) and GY and RGS ($r = 0.76$, $p \leq 0.01$). Correlation coefficients between other monthly rainfall amounts and GY were positive, but not significant. Essentially, the amount of rainfall influenced the soybean GY, especially distribution of rainfall within growing season. *Bošnjak (2004)* has found highly significant correlation between GY of soybean and RGS, as well as between GY and total rainfall in summer months (June, July and August). *Vidić et al. (2009)* have found highly significant

correlation between GY of soybean and amount of rainfall in July and early August. Contrary, *Milošević et al. (2015)* have found that GY did not show significant correlation with rainfall characteristics during long period in Vojvodina (1949-2013). *Teasdale and Cavigelli (2017)* stated that RGS in Beltsville (Maryland, U.S.A.) had the highest correlation with soybean GY.

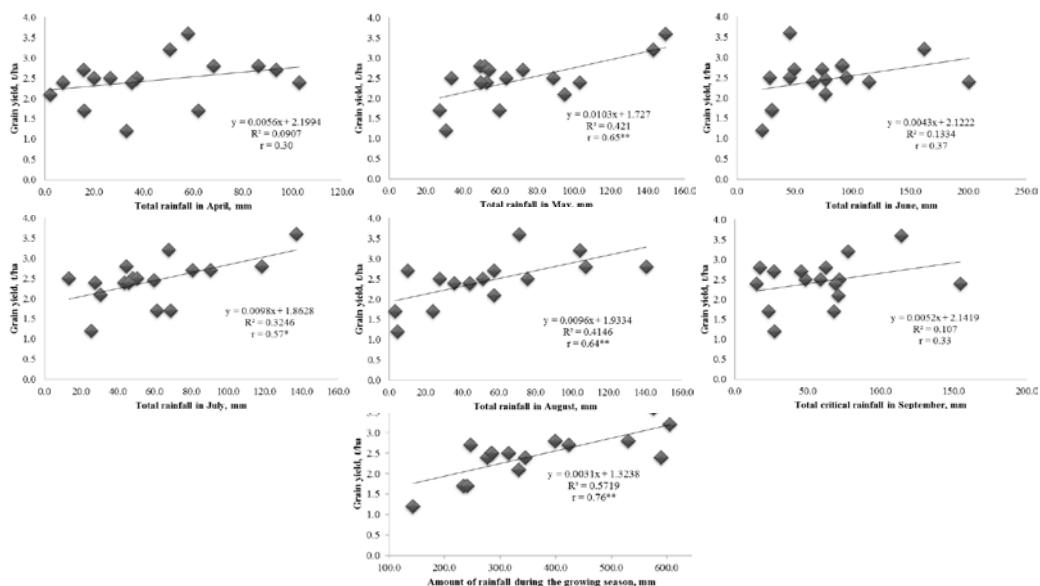


Figure 1. Regression result on the effect of rainfall characteristics on soybean grain yield

Generally, the soybean GY was unstable over the period of 16 years. Rainfall in May, July and August appeared to be the most dominant factor affecting the soybean GY in Vojvodina region. Thus, the higher amount of rainfall during these months would be expected to increase yields. It would be best to irrigate soybean crops from early-July to mid-August, when the most critical stages of grain development occur. Under these conditions soybean could form a large number of pods per plant and large seeds.

Conclusions

In order to achieve a more stable yield, it is necessary to develop cultivars that tolerate water stress. Our study highlights that the variability in soybean production is strongly associated with rainfall during growing season, particularly

in May, July and August. For this reason, farmers should take advantage of all water resources using proper land management, genotypes suitable for this area and proper cropping measures, especially irrigation. Furthermore, as the Vojvodina is major contributor to soybean production in Serbia, our results have significant implications for animal productivity and animal feed security. Our study is important in explaining GY variability. It is necessary overcome the unstable soybean production, ensure stable yield in future, and develop strategies to stabilize food/feed supply and security.

Efikasnost korišćenja padavina i prinos zrna soje u uslovima prirodnog vodnog režima u Vojvodini

Violeta Mandić, Zorica Bijelić, Vesna Krnjaja, Aleksandar Simić, Dragana Ružić Muslić, Vesna Dragičević, Veselin Petričević

Rezime

Padavine su jedan od najvažnijih faktora spoljašnje sredine koji utiče na produkciju useva u uslovima suvog ratarenja. U Republici Srbiji, soja se proizvodi u uslovima prirodnog vodnog režima, pa je praćenje efikasnosti korišćenja padavina (RUE) neophodno za efikasno upravljanje proizvodnjom. Cilj istraživanja bio je da se proceni efekat količine padavina tokom vegetacionog perioda i prosečnih mesečnih padavina na prinos zrna soje u Vojvodini tokom šestnaestogodišnjeg perioda (2000-2015). Distribucija padavina tokom vegetacionog perioda nije bila zadovoljavajuća i nepovoljno je uticala na ekspresiju genetičkog potencijala rodnosti sorti. Deficit padavina tokom vegetacionog perioda soje ograničile su faze reproduktivnog razvoja i dovele do redukcije prinosa. Koeficijenti varijacije pokazuju da se količina padavina tokom vegetacionog perioda i srednja mesečna količina padavina umereno menjaju iz godine u godinu. Regresijske jednačine su pokazale da se prinos zrna povećavao sa količinom padavina. Prinos zrna je u jakoj pozitivnoj korelaciji sa količinom padavina tokom vegetacionog perioda, u maju, julu i avgustu. S obzirom da su količina i raspored padavina u toku vegetacionog perioda kritična determinanta za prinos zrna, treba razvijati i gajiti sorte soje sa kraćim vegetacionim periodom da bi se obezbedila maksimalna iskorišćenost padavina.

Ključne reči: korelacija, regresija, prinos zrna, padavine, soja, Vojvodina

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