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Original scientific paper

EVALUATION OF DIFFERENT SIGMOIDAL GROWTH MODELS AND CLIMATE PARAMETERS FOR DRY MATTER ACCUMULATION OF OAT

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Coşkun Y. (2018): *Evaluation of different sigmoidal growth models and climate parameters for dry matter accumulation of oat*.- Genetika, Vol 50, No.3, 1045-1054.
The monitoring of the biological growth of field crops is important for planning and scheduling agricultural applications. In order to assess biological growth pattern and, dry matter accumulation of Yeniçeri oat variety were obtained in Çanakkale conditions in 2012-2013 and 2013-2014 growing seasons with continuous plant samplings from seedling emergence until seed maturation. Gompertz, Logistic, Logistic Power, Weibull, and Ratkowsky sigmoidal growth models are fitted to actual growth data and their predictions were compared. Results suggested that all sigmoidal growth models successfully explained oat dry matter accumulation a high R^2 values (over 99%) and low mean square errors, Weibull model fitted lower than others for first year with an R^2 value under 99%. Dry matter accumulation was also investigated as a result of average temperature and precipitation with stepwise regression. Results indicated that average weather temperature has a similar pattern across both growing seasons and has a major influence on dry matter accumulation.
Keywords: dry matter, growth models, oat, stepwise regression, temperature

INTRODUCTION

Oat (*Avena sativa* L.) is a plant in human and animal nutrition (BATALOVA *et al*., 2016). Besides being animal feed and human food; oats have gained considerable importance in recent years due to the increased use areas in the pharmaceutical and cosmetic industries. The most important purpose of oat cultivation for grains is to obtain high grain yield. However, oat is also an important feed plant for growing purposes (SABANDUZEN and AKCURA, 2017).

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Winter type oat growth begins with germination in spring but slowly reduces and nearly stops during winter. An exponential growth phase is triggered in early spring when precipitation and overall temperature rises, causing an “awakening” from winter stagnation and rapidly increases plants total biomass, forming an “s” shaped curve. Just like all cold climate cereals, generative growth significantly gains speed with the initiation of heading stage, when vegetative growth is no longer a priority. Hence, the exponential growth phase in oat is not continuous, it reduces speed in later stages alike many plants, which means overall growth pattern can be represented better with sigmoidal growth models.

Sigmoidal growth curves have been used to fit biological growth data widely, some of them were specifically created to be used to study growth, like logistic curve in 19th century (KINGSLAND, 1982) and RICHARDS (1959) when others were used to explain other events that weren’t related to agriculture, like Gompertz equation (GOMPERTZ, 1825; WINSOR, 1932) which were originally used to model human mortality in 1825 (SCHABENBERGER and PIERCE, 2001). Literature of using sigmoidal growth curves to explain biological growth varies greatly by subjects in agriculture, both on animals (AGGREY, 2002; CANAZA-CAYO *et al*., 2015; SOUZA *et al*., 2017) and plants, containing many examples. When studying plant growth, many researchers preferred to monitor either plant height (an indicator of plant dry matter accumulation) or plant dry matter increases over time with evenly spaced observations to reach meaningful physiological conclusions (HEADY, 1957; KARADAVUT and OKUR, 2008; PAINE *et al*., 2012). Although these parameters are relatively simpler to measure, they also can be used to calculate more complex data such as green area index and leaf area index (ROYO *et al*., 2004; LABBAFI *et al.*, 2017). The most important climate factors affecting plant development are precipitation and temperature (KAYA and ALADAG, 2009). In this context, there is also a difference in plant development if temperature and precipitation are different according to years. ŠEKULARAC *et al*. (2017) reported that there was no correlation between the values of gluten index and meteorological factors such as average temperature and total precipitation during the phenophase of grain filling, and in the period from the beginning of flowering until the harvest in bread wheat. It can be accepted that quadratic regression model appropriately fits the process of dry matter accumulation till anthesis in winter wheat (PRŽULJ and MOMČILOVIĆ, 2011). Gompertz, Logistic, Logistic Power and Richards sigmoidal growth models successfully explained triticale dry matter accumulation over 98 % R^2 values and low mean square errors. Dry matter accumulation was also investigated as a result of average temperature, precipitation, growth degree days and cumulative growth degree days with stepwise regression. Results indicated that average weather temperature had had a major influence on dry matter accumulation (HOCAOGLU and COSKUN, 2018).

MATERIALS AND METHODS

Material and Field Trials

Field trials were conducted in Çanakkale Onsekiz Mart University Agricultural Experiment Station in Dardanos, Çanakkale in two consecutive growing seasons (2012-2013 and 2013-2014) in the same plot. Yeniçeri oat variety was used as plant material. It was registered by Bahri Dagdas International Agricultural Research Institute in 2013. Yeniçeri was reported having acceptable grain and biomass yield, disease resistance, high gluten index, drought and cold resistance (ERCAN *et al*., 2016; NANELI and SAKIN, 2017; SABANDUZEN and AKCURA, 2017; ANONYMOUS, 2018).

Seed for field trials were sowed with seed planter in 7 November 2012 and 30 October 2013 in the first and second year of experiment, respectively. Average temperature and precipitation data of Çanakkale suggested a warm and temperate climate. It is classified as Mediterranean hot climate (Csa) in Köppen Gauger climate classification as mentioned by PEEL *et al*. (2007). Soil analysis showed that experimental area had loamy texture with low salinity and were slightly alkaline pH (7.9) with low organic matter (around 1%). Potassium content was found very high (41.3) and phosphorus and iron concentrations were lower than usual, 2.4 and 3.12 ppm respectively. Study area also contained adequate amounts of Copper (1 ppm), Manganese (2.36 ppm) and Zinc (4.08 ppm).

Oat plots were conducted with 500 plants m^{-2} density in 6 m^2 plots with 8 rows each year. 7 kg da^{-1} N fertilization was applied with two splits, one with sowing (2.7 kg da^{-1}) and another with the beginning of tillering stage (4.3 kg da^{-1}) in ammonium nitrate form. Phosphor fertilization was applied in Di ammonium phosphate form along with sowing, at 6.9 kg da^{-1} P_2O_5. Weed control was maintained by hand.

Oat plants within plots were continuously sampled with one week intervals beginning from seedling emergence for 27 weeks in first and second years of experiment, respectively. Each sampling consisted of 5 randomly chosen oat plants to be collected and segregated into roots, stems, leaves, (spikes also are categorized after ear emergence) each week. Fresh plant materials were put in drying oven at 60°C for 48 hours (JONES, 1981), providing enough time for plant samples to reach a constant value, then dry weights were measured in laboratory. Dry weight averages of five samples for one sampling date were used as actual growth data. Since our focus were to evaluate vegetative growth and compare sigmoidal growth models, plant samplings ceased after majority of plants reached ripening "Zadoks 90" (ZADOKS *et al*., 1974) when vegetative activity of oat were no longer a consideration.

Fitting Growth Curves

Gompertz (1), Logistic (2), Logistic Power (3) Ratkowsky (4), and Weibull (5) growth curves (Table 1) fitted weekly dry weight measurements of oat variety Yeniçeri on raw data. Mathematical models of these sigmoidal growth curves are shown in Table 1. Growth curve parameters and predictions were estimated for each model using actual data with Curve Expert v. 1.6 (HYAMS, 2011). Coefficient of determination (R^2), standard error values of each growth curves were used for comparison.

Table 1. Growth Models

Gompertz	$y = ae^{-e^{b-cx}}$	(1)
Logistic	$y = a/(1 + be^{-cx})$	(2)
Logistic Power	$y = a/(1 + (x/b)^c)$	(3)
Ratkowsky	$y = a/(1 + e^{b-cx})$	(4)
Weibull	$y = a - be^{-cx^d}$	(5)

y: dry weights at a measurement, a: asymptotic dry weight, b: growth rate, c: inflection point, d: shape parameter, x: measurement date, e: natural logarithm base.

Stepwise Regression

Since biomass growth of plants are closely associated with weather temperature and precipitation, effects of meteorological conditions of two years on dry matter accumulation of oat were investigated using Stepwise regression in Minitab 17 (MINITAB 17 STATISTICAL SOFTWARE, 2010). Climate data consisted of daily average temperatures and precipitations were acquired from Turkish State Meteorological Service. Daily average temperatures presented as the average of multiple measurements for one day (ANONYMOUS, 2015) upon which sum of Growth Degree Days (GDD) values regarding each measurement interval (measurement day and previous 6 days) and cumulative GDD accumulations were calculated (MCMASTER and WILHELM, 1997). Daily average temperatures, GDD, cumulative GDD and precipitations are used as predictors for two growing seasons separately when actual dry matter accumulation of oat were the dependent variable. In order to assess multicollinearity, variance inflation factors are calculated for each variable as the reciprocal of the inverse of coefficient of determination (GRAHAM, 2003).

RESULTS AND DISCUSSION

Average temperatures across 2012-2013 and 2013-2014 growing seasons showed a high and positive correlation (0.834). Precipitation in first year was mainly congregated before spring, mainly in December (Table 2). In Çanakkale, rain mainly falls in winter with a very little or no direct effect on dry matter accumulation, as seen in first year when there was no significant precipitation recorded after 19 April 2013. Precipitation in second year was considerably lower and showed a different distribution than the first year (Table 3) which also showed poor correlation (Table 5).

Table 2. Dry matter accumulation of oat plants (DM) and cumulative growth degree days (CumGDD) with average temperature of sampling date (Temp), total precipitation (Prec), growth degree days accumulation (GDD) between two consecutive samplings in 2012-2013 growing season.

Sampling No	Date	Temp(°C)	Prec(mm)	GDD(°C)	CumGDD(°C)	DM(g)
1	14/12/2012	4.70	60.00	55.50	136.60	0.058
2	21/12/2012	2.70	43.80	39.90	176.50	0.062
3	28/12/2012	12.30	0.00	59.30	235.80	0.078
4	04/01/2013	8.20	0.20	59.10	294.90	0.112
5	11/01/2013	10.00	6.20	31.90	326.80	0.156
6	18/01/2013	12.30	66.80	72.20	399.00	0.156
7	25/01/2013	11.80	48.00	91.60	490.60	0.265
8	01/02/2013	7.90	52.80	37.60	528.20	0.330
9	08/02/2013	11.30	27.40	89.90	618.10	0.844
10	15/02/2013	6.00	80.40	58.30	676.40	1.212
11	22/02/2013	8.50	15.80	41.20	717.60	1.822
12	01/03/2013	7.10	11.40	63.60	781.20	2.187
13	08/03/2013	11.40	8.20	63.10	844.30	2.841
14	15/03/2013	14.50	2.20	100.20	944.50	3.783
15	22/03/2013	8.30	15.80	41.20	985.70	6.071
16	29/03/2013	11.20	21.00	73.30	1059.00	8.305
17	05/04/2013	15.50	10.20	102.10	1161.10	10.811
18	12/04/2013	15.00	65.40	94.50	1255.60	13.538
19	19/04/2013	11.40	14.10	92.10	1347.70	18.544
20	26/04/2013	20.20	0.60	113.00	1460.70	26.016
21	03/05/2013	18.60	0.00	133.20	1593.90	31.586
22	10/05/2013	18.50	3.80	133.80	1727.70	37.000
23	17/05/2013	21.50	1.60	130.20	1857.90	40.596
24	24/05/2013	20.10	0.20	152.10	2010.00	41.440
25	31/05/2013	20.70	0.00	142.40	2152.40	40.390

Table 3. Dry matter accumulation of oat plants (DM) and cumulative growth degree days (CumGDD) with air temperature of sampling date (Temp), total precipitation (Prec), growth degree days accumulation (GDD) between two consecutive samplings in 2013-2014 growing season.

Sampling No	Date	Temp(°C)	Prec(mm)	GDD(°C)	CumGDD(°C)	DM(g)
1	13/12/2013	3.00	9.70	27.60	171.40	0.0910
2	20/12/2013	4.10	0.20	40.90	212.30	0.1400
3	27/12/2013	13.10	0.00	49.10	261.40	0.2000
4	03/01/2014	8.80	0.20	58.00	319.40	0.2440
5	10/01/2014	7.70	0.00	54.10	373.50	0.4650
6	17/01/2014	11.90	1.60	69.30	442.80	0.4660
7	24/01/2014	11.30	10.80	91.90	534.70	0.7670
8	31/01/2014	5.30	41.60	49.80	584.50	1.3220
9	07/02/2014	7.80	0.00	48.00	632.50	1.3220
10	14/02/2014	11.30	0.40	87.00	719.50	1.5140
11	21/02/2014	11.40	0.00	74.10	793.60	2.2420
12	28/02/2014	8.00	0.00	50.40	844.00	3.7390
13	07/03/2014	10.60	56.00	81.60	925.60	4.5280
14	14/03/2014	8.10	13.60	46.70	972.30	6.4140
15	21/03/2014	14.80	0.00	93.00	1065.30	8.9780
16	28/03/2014	13.90	10.00	91.90	1157.20	10.0000
17	04/04/2014	13.60	0.80	85.70	1242.90	14.9690
18	11/04/2014	12.50	25.60	97.60	1340.50	17.0000
19	18/04/2014	12.90	28.20	98.00	1438.50	20.0000
20	25/04/2014	16.90	9.40	117.80	1556.30	22.8610
21	02/05/2014	17.40	47.40	111.70	1668.00	25.2000
22	09/05/2014	15.00	3.20	116.30	1784.30	32.2000
23	16/05/2014	17.90	2.40	129.50	1913.80	42.1980
24	23/05/2014	21.90	7.40	140.80	2054.60	50.2110
25	30/05/2014	19.70	4.40	156.10	2210.70	48.2110

Dry matter accumulation of Yeniçeri on both seasons was highly correlated (0.988) which may be due to the influence of average temperature rather than precipitation regimes. Dry matter accumulations also reached a rapid growth phase after 22 March 2012 (16th sampling) in the first year and 21 March 2013 (17th sampling) in the second year (Table 2 and 3). Even though, average temperatures of exact sampling dates didn't clearly reflect this increase. Association in timing of rapid increase in dry matter in both years indicates a positive relation between weather temperature and dry matter accumulation in oat. Although precipitation didn't show any association with neither as a pattern, but it there were continuous rainfall in first year (Table 2) and considerable amount of rainfall recorded 15th and 16th sampling dates in second year (Table 3), prior to rapid growth phase of dry matter.

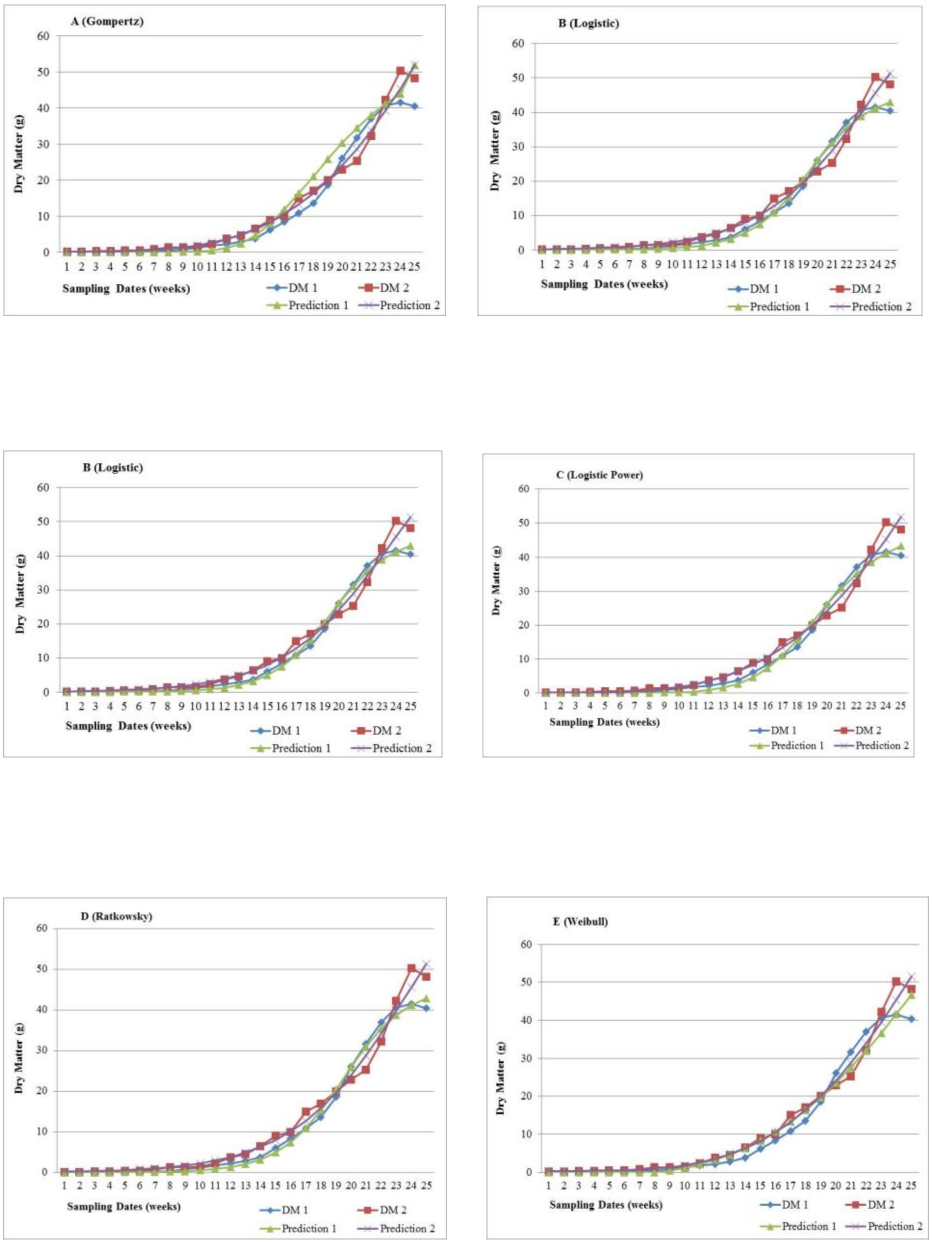

Figure 1. Dry matter accumulation and different curve models through 1st and 2nd years

Table 4. Correlations of dry matter (DM), average temperature (Temp), growth degree days (GDD), cumulative growth degree days (CumGDD) and precipitation (Prec) and p values of both experiment seasons (year 1 and year 2).

	DM1	Temp1	GDD1	Cum GDD1	Prec1	DM2	Temp2	GDD2	Cum GDD2
Temp1	0.8540**								
GDD1	0.8801**	0.8983**							
CumGDD1	0.9407**	0.8481**	0.8624**						
Prec1	-0.4732*	-0.5229**	-0.3975*	-0.4657*					
DM2	0.9800**	0.8382**	0.8683**	0.9421**	-0.4584*				
Temp2	0.8234**	0.8330**	-0.7595**	0.8509**	0.4664*	0.8330**			
GDD2	0.8785**	0.7991**	0.7778**	0.9080**	-0.3334^{ns}	0.8874**	0.9260**		
CumGDD2	0.9346**	0.8422**	0.8514**	0.9994**	-0.4626*	0.9421**	0.8510**	0.9114**	
Prec2	0.0827^{ns}	0.1136^{ns}	0.0180^{ns}	0.0887^{ns}	0.1531^{ns}	0.0445^{ns}	-0.0023^{ns}	0.0923^{ns}	0.1654^{ns}

Table 5. Relations and statistics of the stepwise analysis.

	Equation	R^2
Year 1	DM = -14.96 + 0.1131 GDD + 0.0180 CumGDD VIF (GDD) = 3.29 VIF (CumGDD) = 1.40 P<0.01	90.33%
Year 2	DM = -12.156 + 0.0246 CumGDD VIF (CumGDD) = 1.002 P<0.01	88.76%

DM: Dry Matter, GDD: Growth Degree Days, CumGDD: Cumulative Growth Degree Days, VIF: Variance inflation factor

Growth Model Comparison

Standard errors of growth curves were 1.07025 and 2.663982 in first year and 1.70539 and 1.76148 in second in Logistic and Weibull models respectively, which also all models except of Weibull model in second year had high R^2 (up to 99%) for both experiment years. Standard error of Logistic power (1.32324 in first and 1.73430 in second) and Gompertz (1.62262 in first and 1.73028 in second years) Ratkowsky model (1.07025 in first and 1.70539 in second years) were relatively higher. Highest standard errors of first year was acquired by Weibull model (2.66398), also in accordance with its lower R^2 (98%) indicating its limitations of explaining dry weight growth of oat (Table 6.).

According to the results mentioned above, all growth curves except Weibull adequately described growth pattern of oat by generally high R^2 with lower Mean Square Error (MSE) values. Sigmoidal growth curves often reported as fitting the biological growth data inseparably, a good example can be seen in AGGREY (2002)'s findings, such that Richards and Gompertz curves explaining chicken growth with equal power. Ratkowsky and Logistic curves had the best fit with highest R^2 and lowest MSE in both years, but closely followed by Weibull, Logistic Power and Gompertz which also adequately described biological growth of oat. A previous study of KARADAVUT (2009) compared several growth curves on three different triticale cultivars grown in irrigated conditions and reached the conclusion of Richards and Weibull models explained the dry weight growth best. Accordingly, Richards growth curve was used successfully to model snap beans (LIETH and REYNOLDS, 1986) and dry matter growth of silage and seed corns (KARADAVUT *et al*., 2010).

Table 6. Curve fitting statistics of dry matter accumulation of oat plant.

First Year	Gompertz	Logistic	Logistic Power	Ratkowsky	Weibull
R^2	0.99472	0.997707	0.99649225	0.99771	0.986360
Standard error	1.62262	1.070250	1.3232392	1.07025	2.663982
a	55.78876	45.894815	49.3813069	45.8948	115.82784
b	4.41344	10793.017	19.7477528	9.28667	116.93681
c	0.23359	0.477444	-8.2685025	0.47744	0.0000051
d					3.58439
Second Year	**Gompertz**	**Logistic**	**Logistic Power**	**Ratkowsky**	**Weibull**
R^2	0.99452	0.99468	0.99449	0.99468	0.99458
Standard error	1.73028	1.70539	1.73430	1.70539	1.76148
a	379.49346	87.87665	295.64093	87.87540	123.59581
b	2.32162	527.85815	37.14520	6.26885	123.26926
c	0.06534	0.26437	-3.91235	0.26437	0.0000009
d					4.12172

We have taken the following messages from the current work:

Meteorological data suggests that there was little variation among two consecutive years in terms of overall temperature patterns, a high correlation can be seen between average temperatures of both seasons. Average temperature plays an important role in dry matter accumulation and may be used as a main indicator to explain in season growth patterns. This conclusion excludes the soil factor, because plant samples in our study were acquired from the same plot in both years.

Even though there weren't enough evidence in our study to evaluate how plant growth is affected by different precipitation regimes, it is apparent in both years that increase of weather temperature exceeding 10°C in daily average in mid-March may have triggered rapid biological growth of oat. This is probably with an interaction of precipitation and other climate and soil factors that remains unclear.

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OCENJIVANJE RAZLIČITIH MODELA SIGMOIDALNOG RASTA I KLIMATSKIH PARAMETARA ZA AKUMULACIJU SUVE MATERIJE KOD OVSA

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IZVOD

Praćenje biološkog rasta useva je važno za planiranje poljoprivrednih radova. U cilju procene biološkog rasta i akumulacije suve materije sorte ovsa Yeniçeri, postavljeni su ogledi u Çanakkale-u, tokom sezona 2012-2013 i 2013-2014, za određivanje akumulirane suve materije, sa kontinuiranim uzorkovanjem biljaka od faze klijanaca do faze zrelog zrna. Gompertz, Logistic, Logistic Power, Weibull i Ratkowsky sigmoidalni modeli rasta su bili saglasni sa dobijenim podacima za porast, pa su upoređivane njihove procene. Rezultati ukazuju da su svi modeli sigmoidnog rasta uspešno objasnili akumulaciju suve materije sa visokim vrednostima R^2 (preko 99%) i sa malim greškama sredine kvadrata, s tim sto je Weibull-ov model bio manje primenljiv za prvu godinu ispitivanja, sa R^2 vrednostima ispod 99%. Akumulacija suve materije takođe je istraživana kao rezultat prosečne temperature i padavina postupnom regresijom. Rezultati pokazuju da prosečna temperatura bila slična u obe vegetacione sezone i da ima najveći uticaj na akumulaciju suve materije.

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