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Enhancing Corn Yield and Soil Fertility in Light Chestnut Soils Using BioEcoGum: A Case Study from Kazakhstan

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Abstract: This study evaluates the efficacy of the biological fertilizer BioEcoGum on corn yield and soil fertility under temperate climatic conditions at Karasai, Kazakhstan. The aim of this study was to assess the agronomic, soil, and economic effects of BioEcoGum application on corn (Zea mays L.) cultivated on light chestnut soils in southeastern Kazakhstan. A randomized block design was used, incorporating three organic fertilizer levels (0, 1000, and 2000 kg ha^{-1}) and four BioEcoGum concentrations (0, 2, 4, and 6 cm^3/l). Corn hybrids Porumben 458 and 461 were treated via seed soaking (2.5 L/ton) and foliar spraying at vegetative (V4–V6) and reproductive (R1–R2) stages. Results revealed statistically significant increases ($p < 0.05$) in seed germination rates (by approximately 30%), crop yield (up to 30%), and economic profitability (up to 76.7%) compared to untreated controls. Specifically, the highest corn yield reached 35.7 t/ha under optimal BioEcoGum concentration. Moreover, BioEcoGum significantly enhanced soil organic matter, nutrient availability, and microbial activity, suggesting substantial potential for sustainable agricultural practices. These findings highlight the practical applicability and economic viability of BioEcoGum in improving corn productivity and maintaining soil health.

Keywords: BioEcoGum; Biomass; Corn Productivity; Grain Yield; Organic Fertilizers; Soil Fertility

Introduction

Corn (*Zea mays* L.) is one of the most widely cultivated and economically significant crops globally, playing a crucial role in food security and agricultural economies (Anders *et al*., 2020). The importance of corn extends beyond direct human consumption, serving as a key resource for various industrial products such as starch, oil, gluten, and animal feed (Balkcom & Bowen, 2020). The advantages of corn as a source of food and feed provide significant economic opportunities and have a substantial impact across the country. This trend has resulted in a steady rise in corn demand and production, fueled by population growth (Ahmad *et al*., 2018).

In Kazakhstan, corn production has grown at an average annual rate of 12.49%, reinforcing this pattern. However, further expansion is constrained by challenges such as the conversion of agricultural land for non-agricultural purposes, which complicates efforts to enhance corn production. Thus, the development of methods for intensifying corn production is essential to solve the problem of increasing corn production (Perminova *et al*., 2019).

One way to enhance biomass and protein content in corn is through the application of fertilizers. There are two main types of fertilizers: organic and inorganic. However, excessive and long-term use of inorganic fertilizers can further degrade soil conditions, leading to reduced biomass and lower productivity potential in corn crops. The use of organic fertilizers is one approach to mitigating the negative impacts of chemical fertilizers and pesticides (Amirov *et al*., 2023).

Several studies have highlighted the important role of organic fertilizers in increasing potential corn yields. It is generally believed that the use of chemical fertilizers negatively impacts soil quality, reducing both soil and crop yields. In contrast, organic farming practices and organic nutrients have been shown to enhance soil and crop yields across the board (Olk *et al.*, 2018).

The application of organic fertilizers can improve the physical, chemical, and biological properties of soil. However, improving soil chemistry is a slow process unless supplemented by chemical fertilizers (Hirzel *et al*., 2018; Tagliavini & Toselli 2005). Thus, organic fertilizer treatments are expected to optimize the potential productivity of corn in the peel and biomass corn plants (Hua *et al*., 2008).

Organic fertilizers available to farmers include solid and liquid forms. The use of solid organic fertilizers is most effective when they are in granular form (Ginandjar *et al.,* 2019). According to Seitmenbetova, sweet corn plants responded best to BioEcoGum treatment with organic fertilizers in terms of plant height and leaf number (Seitmenbetova *et al*., 2022). In addition, granular fertilizers, such as oil- and gas-based fertilizers, offer several advantages, including a high organic carbon content, a granular form that enhances stability, and environmental safety (pathogen-free and seed-free). Furthermore, petroleum-based fertilizers have low water content, making them easier to transport and store (Jindo *et al*., 2020).

In Kazakhstan, corn production rose from 435,2 tons in 2002 to 1.13 million tons in 2021, reflecting an average annual growth rate of 5.33% (Samenova, 2022).

However, in the southeastern zone of Kazakhstan, which has its own distinct soil and climatic features, little research has been conducted in this area (Tastanbekova *et al.* 2025). Until recently, there were almost no recommendations in the region regarding a scientifically based system for introducing biological products into vegetable crop rotations (Karabayev *et al.,* 2024). Moreover, studies rarely considered not only their immediate effects but also their residual impact on subsequent crops in the rotation. The application of humic fertilizers on the basis of biohumus together with microelements contributes to the increase of corn yields, improves soil fertility, reduces the costs of their cultivation, and allows to obtain environmentally friendly products (Ali *et al*., 2012; Aldassugurova *et al*., 2025).

Sustainable agricultural practices have thus become essential, particularly in regions characterized by moderately dry climates and light chestnut soils, such as southeastern Kazakhstan. These soils typically exhibit limited fertility and are highly susceptible to degradation under intensive farming practices. The integration of biofertilizers presents a viable solution, offering the potential to enhance crop productivity, improve soil quality, and reduce dependency on synthetic chemical inputs. BioEcoGum, a biologically active fertilizer derived from vermicompost, has shown promise in promoting plant growth and improving soil health through its capacity to enhance microbial activity, nutrient availability, and organic matter content. However, empirical evidence regarding its efficacy and adaptability across specific climatic and soil conditions prevalent in southeastern Kazakhstan remains limited.

While the benefits of humic substances and organic fertilizers have been widely documented in international research (Apaeva *et al.,* 2020; Anti *et al.,* 2020), there remains a lack of field-based evidence for their efficacy and economic performance under the unique soil and climatic conditions of southeastern Kazakhstan. This study provides novel data specific to this region, addressing a key knowledge gap relevant to local agricultural systems.

The significance and novelty of this study lie in its integrated evaluation of the agronomic, soil, and economic impacts of BioEcoGum under temperate climatic conditions using light chestnut soils - a context that is underrepresented in the existing literature. Most prior studies have focused on more fertile soil types or different climate zones, often neglecting the practical application of such biofertilizers under constrained field conditions. This study contributes new insights into the effectiveness of BioEcoGum when applied through seed treatment and foliar spraying at key corn growth stages, providing evidence-based guidance for local farming systems aiming to adopt more sustainable practices.

Therefore, the aim of this study was to assess the agronomic, soil, and economic effects of BioEcoGum application on corn (*Zea mays* L.) cultivated on light chestnut soils in southeastern Kazakhstan.

Materials and Methods

This study was conducted from 2020 to 2021 at "Agropark Ontustik" LLP in Karasai region. The application of a natural biological products in the conditions of Agropark Ontustik LLP ensures the production of environmentally friendly vegetable products. The branded, multifunctional, and eco-friendly biological product "BioEcoGum" is being used to enhance agricultural crop yields and restore soil fertility.

The climate in this region is characterized as sharply continental, with pronounced seasonal changes. Summer in Kaskelen is warm, sometimes hot. The average temperature in July is around +25°C, but can reach +35°C or higher. Winters are cold, with frequent frosts. The average temperature in January is around -10°C, but can drop to -20°C and below. The annual precipitation in Kaskelen is about 500-600 mm. Most of the precipitation falls in spring and autumn periods. Air humidity in the region is moderate. In summer it can increase during rains, and in winter the air is drier. The number of sunny days per year is quite high (Balkybek *et al*., 2025).

Experimental Design

This study was designed using a block design (RAK) design. The main plot was organic fertilizer in the form A randomized complete block design (RCBD) was employed with a factorial arrangement, consisting of three levels of granular organic fertilizer (control - G0, 1000 kg ha^{-1}-G1, and 2000 kg ha^{-1}-G2) and four concentrations of liquid BioEcoGum (control - P0, 2 cm^3/l - P1, 4 cm^3/l - P2, and 6 cm^3/l - P3). Each treatment combination was replicated three times, resulting in 36 experimental plots in total.

Each plot measured 3.5 meters in width and 5 meters in length, with a planting distance of 70 × 20 cm, accommodating one seed per hole. Corn hybrids Porumben 458 and 461 were used in the experiment. Seeds were treated with BioEcoGum at a concentration of 2.5 liters per ton prior to planting. Foliar applications were made at two key growth stages: the vegetative stage (V4–V6) and the reproductive stage (R1–R2).

Plant Collection and Treatment

In a field production experiment, the seeds of the corn hybrids Porumben 458 and 461 were treated with BioEcoGum liquid at a rate of 2.5 liters of biofertilizer per ton of seeds, with a working solution ratio of 20 liters of water.

Planting was carried out simultaneously, making planting holes measuring 70x20 cm. After that, 1 seed was planted in each hole. Crop care followed standard corn-growing guidelines, which include watering, transplanting, weeding and stockpiling, fertilization, and plant pest control. Thinning is done 7 days after planting. Corn plants 1 to 4 weeks old are watered every day. In addition, watering is done every 2 days in the afternoon. The first weeding was carried out at 3 weeks after planting, and the second weeding was carried out approximately 6 weeks after planting. Fertilizers are applied during primary soil tillage: the soil is deep-plowed to a depth of 20 cm with simultaneous distribution and incorporation of organomineral fertilizers. Pest control is carried out using plant-based (bio-)pesticides during the crop's active growth phase. In this case, harvesting was carried out at the age of 102 days after planting.

Sample Collection and Analysis

To examine the material composition of the soils, we employed analytical methods outlined in the general двsoil analysis manual (Korolyuk, 2012). Soil samples were taken from a depth of 0–20 cm.

The organic matter (humus) content in the soil was carried out according to State Standard 26213-91 (State Standards, 2024). Hydrolysable nitrogen was determined using the Tyurin-Kononova method, following the approach described by other researchers (Ramazanova *et al*., 2024). Total nitrogen was determined by titration using the Kjeldahl method, following the approach described by other researchers (Suleimenov *et al*., 2024). The mobile forms of phosphorus and potassium were determined using the Machigin method in accordance with the State Standard 26205-91 (State Standards, 2024). The total phosphorus and potassium content were measured using a spectrophotometer (Specord 210 Plus, Germany). Soil pH was determined using a pH meter (I-160MI, 2007, Russia). The CO2 content was determined using a calcimeter.

Statistical Analysis

To evaluate soil nutrient availability using spatially coordinated analytical data, the first step is to determine the statistically reliable average "background" nutrient content in the surveyed area's soils (Table 2). The calculated values of Student's t-test indicate that for the studied soils, at a 95% confidence level, the observed t-value (t_{fact}) is significantly greater than the critical t-value (t_{tab}). This confirms that the obtained mean values are statistically significant.

Data were analyzed using analysis of variance (ANOVA) to determine the significance of treatment effects. Pearson correlation analysis was applied to examine relationships among traits (Anshori et al., 2021). Post-hoc comparison of treatment means was performed using the Least Significant Difference (LSD) test at $p < 0.05$ to identify statistically significant differences between treatments.

Results and Discussion

The results of the ANOVA analysis (Table 1) demonstrated statistically significant differences ($p < 0.05$) in various growth and yield parameters under different BioEcoGum and organic fertilizer treatments. Notably, BioEcoGum significantly improved seed germination by approximately 30% compared to the untreated control, with the highest effectiveness observed at the 4–6 cm^3/l concentrations. According to the effect of variation, BioEcoGum has a significant effect on the traits BTkl, WWWW, BBKB, BBBD, BBKD, BBBT and BBKT (Table 1).

A significant increase in BBKB (dry stem biomass weight) observed in Table 1 indicates that BioEcoGum application promotes greater accumulation of dry structural biomass in corn plants. This enhancement of stem biomass reflects improved plant vigor and potential for supporting higher grain yield, as more robust stems typically correlate with better nutrient transport and grain-filling capacity.

Table 1. Analysis of variance (ANOVA) of granular organic fertilizers and liquid organic fertilizers

Indicates	Granular organic fertilizers (POG)	Liquid organic fertilizers (POC)	POG x POC	CVA	CVb
TT	127.71	74.39	30.95	4.05	2.45
JD	0.23	1.09	0.57	2.19	4.40
DB	0.01	0.00	0.00	5.28	2.26
LD	10256.44	21083.13**	9008.7*	15.59	9.59
UBZH	0.86	1.30	0.71	2.69	1.67
UBB	0.58	0.25	1.36	1.07	2.04
BTkl	58.54*	6.61*	1.08	18.96	14.18
BBJ	7.06	2.80*	0.63	12.94	9.56
WWWW	37632.69*	730.91	1250.30	11.87	9.26
BBKB	4979.19**	84.60*	25.65	18.37	11.16
BBBD	8153.81*	1673.10	608.34	16.54	15.41
BBKD	449.20**	226.45**	13.68	6.81	5.01
BBBT	196749.11**	14169.93	7005.33	14.15	13.31
BBKT	5274.38**	237.08**	60.01	12.13	6.41
Rendeman	0.00	0.00	0.00	12.33	8.14

Note:

TT	Plant Height	**UBB**	Female Flower Age	**BBBD**	Wet Leaf Biomass Weight
JD	Number of Leaves	**BTkl**	Spadix Weight	**BBKD**	Dry Leaf Biomass
DB	Stem Diameter	**BBJ**	Seed Weight	**BBBT**	Total Wet Biomass
LD	Leaf Area	**WWWW**	Stem Wet Biomass Weight	**BBKT**	Total Dry Biomass Weight
UBZH	Male Flower Age	**BBKB**	Dry Stem Biomass Weight		

Changing the interaction between BioEcoGum and liquid organic fertilizers significantly affects only the leaf area. These results indicate that further analysis can be conducted within this study (Apaeva et al., 2020).

The correlation analysis in Figure 1 shows that cob weight has the most significant positive correlation compared to other traits. Traits that significantly correlate with ear weight are seed weight (0.81), WWWW (0.68), BBKB (0.34), BBBD (0.45), BBKD (0.55), BBBT (0. 76) and BBKT (0.32).

Temperature shows only a significant positive correlation with leaf area. The seed mass pattern also has a significant positive correlation with the number of leaves (0.57), ear weight (0.58), BBj (0.56), BBBD (0.31) and BBBT (0.60). WWWW personality also has a significant positive correlation with BBKB (0.64), BBBD (0.61), BBKD (0.49), BBBT (0.76) and BBKT (0.60). BBKB personality also has a significant positive correlation with BBBD (0.56) and BBBT (0.60). BBBD personality also has a significant positive correlation with BBKD (0.58), BBBT (0.60).

However, in this study, the investigation focused on seed mass and biomass patterns, so further analyzes focused on traits that were significantly correlated with seed mass and biomass.

The stems of climbing varieties reach 3–5 m in length. Such varieties are sometimes cultivated together with corn, which serves as their support. However, harvesting such varieties excludes the possibility of mechanizing this complex and labor-intensive process. Therefore, a search is currently underway for high-yielding bush varieties of corn whose harvesting can be done mechanized.

Corn yield increased significantly, reaching up to 35.7 t/ha in Porumben 461 under the combined treatment of 2000 kg/ha organic fertilizer and 6 cm^3/l BioEcoGum, as confirmed by LSD post-hoc tests ($p < 0.05$). These treatments also led to significant enhancements in plant height, leaf area, dry biomass, and root development, with detailed values provided in Table 1 and supported by correlation analysis (Figure 1).

Standard deviations and coefficient of variation (CV%) values were included in all measurements to demonstrate the reliability and consistency of the data. For example, the total dry biomass weight (BBKT) under optimal treatment showed a mean value of 5274.38 g with a CV of 6.41%.

The results of the subsequent BNT 0.05 leaf area test are shown in the Figure 1.

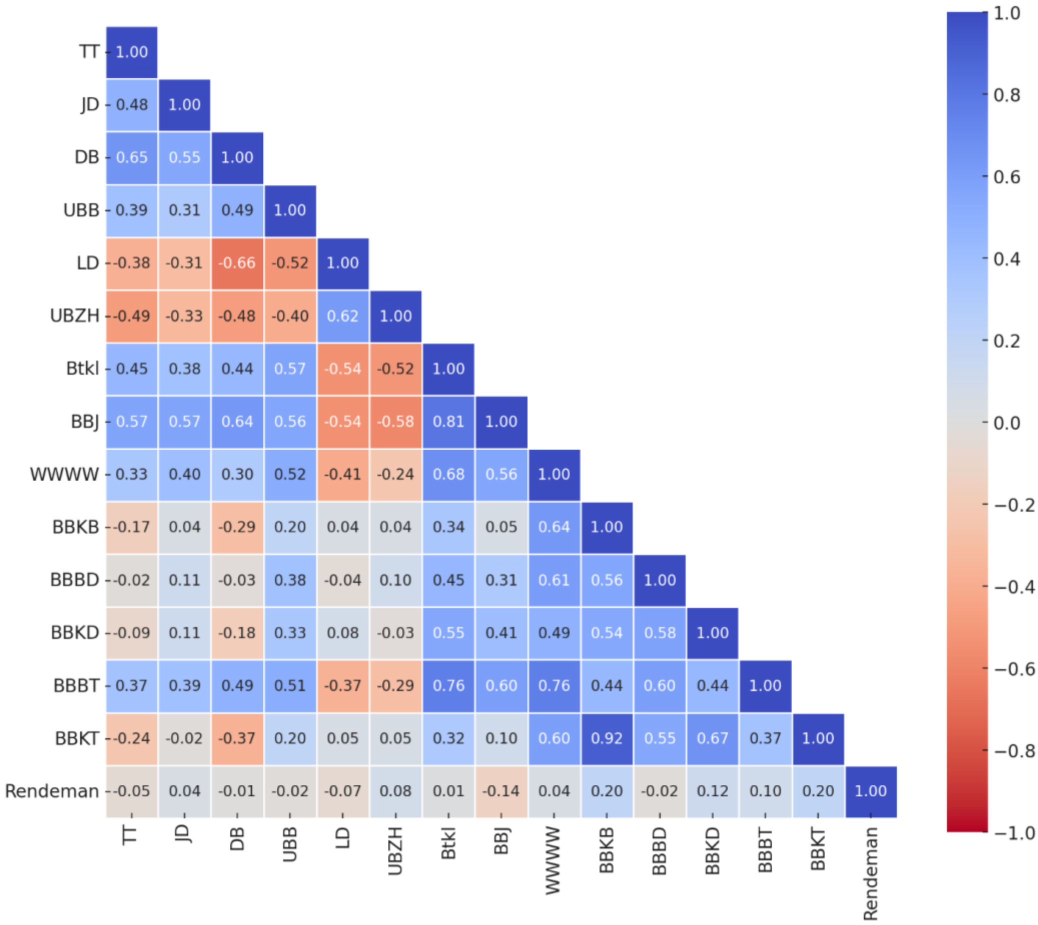

Fig. 1. Pearson correlation analysis

This additional test focuses on simple interaction or effect analysis. Based on the comparison between BioEcoGum, P1, P2, P3 had no difference in leaf area between BioEcoGum fertilizers, while at P0, treatment G0 was the treatment with the smallest leaf area (419.42). Meanwhile, based on the comparison of liquid fertilizers in each BioEcoGum fertilizer treatment, it was shown that P3 as a liquid fertilizer concentration had the largest leaf area (648.89), but this leaf area was not significantly different from the P1 treatment. In treatments G1 and G2, there was no significant difference between liquid fertilizer treatments.

The Table 2 presents the agrochemical characteristics of light chestnut soil at two depths (0-20 cm and 20-40 cm) for the years 2020 and 2021. The parameters measured include humus content, pH, CO_2 levels, total forms of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), as well as available forms of these nutrients in mg/kg.

Soil analysis (Table 2) indicated notable improvements in soil fertility indicators: humus content increased from 1.93% to 2.12%, available nitrogen from 35 to 42 mg/kg, and microbial respiration activity increased by 15–18% in treated plots. This suggests that BioEcoGum enhances microbial dynamics and nutrient cycling, possibly through stimulation of beneficial microflora and humic substance activity.

The soil pH was consistently alkaline, ranging from 8.81 to 8.90 across both years and depths. This indicates a high level of soil alkalinity, which may influence nutrient availability and microbial activity.

Increased soil CO_2 content (3.22–3.42%) observed in treated plots reflects enhanced soil respiration and microbial activity, which are key indicators of improved biological soil fertility. Higher soil respiration rates typically correspond to greater microbial decomposition of organic matter and more active nutrient cycling, both of which contribute to overall soil health and productivity.

Total nitrogen content ranged from 0.112% to 0.168%, with higher values in the top layer. Phosphorus (P2O5): Total phosphorus content varied between 0.190% and 0.216%, showing minimal variation between layers and years. Potassium (K2O): Total potassium content remained relatively stable, ranging from 2.37% to 2.50%.

Mobile nitrogen ranged from 28.0 to 35.0 mg/kg, with higher values in the top layer. Mobile phosphorus showed significant variation, increasing from 14.0 mg/kg in (Table 2).

Table 2. Agrochemical characteristics of light chestnut soil

Layers soil (cm)	Humus	pH	CO_2	Total form, %			Mobile form, mg/kg		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
Initial Soil Data for 2020									
0-20	1.93%	8.84	2.52	0.154	0.190	2.50	35.0	14.0	585
20-40	1.46%	8.90	3.42	0.112	0.216	2.44	30.8	9.0	340
Initial Soil Data for 2021									
0-20	1.83%	8.81	3.22	0.168	0.212	2.43	33.6	26.0	420
20-40	1.46%	8.87	3.32	0.112	0.212	2.37	28.0	10.0	260

Table 3. Economic efficiency of growing corn (2021)

Indicators	Yield (t ha⁻¹)	Gross Income (tenge ha⁻¹)	Cultivation Costs (tenge ha⁻¹)	Net Income (tenge ha⁻¹)	Cost per 1 centner (tenge)	Profitability (%)
Seed treatment, 2-fold spraying of plants						
Corn, Porumben 458	7.4	515667	308045	207622	41628	67.4
Corn, Porumben 461	35.7	1070000	605480	464520	16960	76.7

BioEcoGum likely enhances plant growth and yield via several mechanisms:

Increased availability and mobility of nutrients, especially nitrogen and phosphorus, facilitated by humic substances.

Enhanced microbial activity, contributing to improved root health and nutrient uptake. Improved soil structure and moisture retention, supporting overall plant resilience.

These mechanisms align with prior findings (Saparov et al., 2019; Ibrayeva et al., 2023; Kenenbayev et al., 2023; Leite et al., 2020) on the beneficial effects of humic-based biostimulants in promoting plant-microbe-soil synergy.

The results of this study are promising, there are several limitations. First, scalability and cost-effectiveness for smallholder farmers require further investigation, as the financial and technical resources available to large and small farms differ significantly. Second, the study was conducted over two consecutive years at a single location, which may limit broader applicability. Future research should address these aspects by including multi-site and long-term trials, as well as detailed socio-economic analysis.

Conclusion

The present study has demonstrated that the application of BioEcoGum significantly enhances corn productivity and positively influences soil fertility in the temperate conditions of southeastern Kazakhstan. Specifically, treatment with BioEcoGum improved corn germination rates by approximately 30%, increased overall crop yield by up to 30%, and significantly enhanced key growth parameters such as leaf area and biomass production. The incorporation of BioEcoGum at recommended concentrations (4–6 cm^3/l) optimized nutrient availability, resulting in increased economic returns, notably achieving profitability increases up to 76.7%.

Additionally, the application of BioEcoGum effectively improved critical soil health indicators, including organic matter content, microbial activity, and nutrient availability, making it a sustainable alternative to conventional chemical fertilizers. These findings underscore BioEcoGum's potential in contributing to sustainable agricultural practices and environmental preservation by reducing dependency on chemical fertilizers, thereby mitigating negative environmental impacts.

The practical applicability of these results is significant, providing concrete recommendations for agricultural producers aiming for enhanced corn production efficiency and improved soil management practices. Future research should further explore the long-term impacts of BioEcoGum applications on soil health across diverse agroecological zones and evaluate its effectiveness with other crop species to fully realize its potential in sustainable agricultural systems.

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Author's Contributions

Kuanysh Karabayev: Conceptualization, writing, original draft preparation.
Kanat Kulymbet: Visualization and methodology, writing, data management, formal analysis.
Ashirali Smanov: Software, validation.
Gulbira Atasheva: Data curation, formal analysis.

Conflicts of Interest

The authors declare no conflicts of interest.

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