Research Paper

Soil Quality Enhancement for Sustainable Shallot (Allium ascalonicum L.) Cultivation in Central Kalimantan

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Abstract

Shallot (Allium ascalonicum L.) is an economically valuable horticultural crop for Indonesia's domestic market and rural livelihoods. However, its expansion into Central Kalimantan is constrained by acidic, nutrient-poor soils such as Ultisols and Spodosols, and erratic rainfall. This study aims to develop an integrated soil quality enhancement framework combining liming, organic amendments, and biofertilizers for sustainable shallot cultivation. The research was conducted through descriptive and comparative analysis of soil properties before and after treatment in a 500 m^2 demonstration plot. Laboratory analyses included soil pH, organic matter, cation exchange capacity (CEC), and available phosphorus (P-Bray). Data interpretation used descriptive statistics and literature benchmarking. Results showed that integrated soil management increased soil pH from 4.5 to 6.0, organic matter from 1.2% to 2.8%, CEC from 6 to 12.5 cmol(+)/kg, and available phosphorus from 5 ppm to 18 ppm. These improvements corresponded to potential yield increases of 30–40% under optimal irrigation. The novelty of this study lies in the adaptive integration of biological and chemical amendments tailored for humid tropical acid soils. The findings provide practical insights for sustainable horticulture and local food security enhancement in Central Kalimantan.

Keywords: *Shallot, Soil Quality, Central Kalimantan, Sustainable Cultivation, Integrated Soil Management*

INTRODUCTION

Shallot (*Allium ascalonicum L.*) is a key horticultural crop in Indonesia, serving both domestic consumption and regional economic development. Despite its importance, shallot cultivation remains geographically concentrated in Java, limiting opportunities for agricultural diversification elsewhere.

One of the major constraints to agricultural development in Central Kalimantan is the predominance of acidic soils with inherently low fertility. The mineral soils in this region, particularly Ultisols and Spodosols, often have pH values ranging from 4.0 to 5.0, which is far below the optimum range required for shallot cultivation. Under such acidic conditions, essential nutrients such as phosphorus (P), calcium (Ca), and magnesium (Mg) become less available to plants, while toxic elements like aluminum (Al) and iron (Fe) increase in solubility, inhibiting root development and nutrient uptake. This imbalance poses a serious challenge for shallow-rooted crops like shallots, which are highly sensitive to nutrient stress.

Low organic matter content (<2%) is another major constraint (Hairiah et al., 2011). Organic matter is critical for soil aggregation, water holding, and microbial activity. In shallot cultivation, organic matter deficiency results in poor soil structure and high susceptibility to nutrient leaching. Due to high temperatures and rainfall, organic matter decomposes rapidly, leading to a limited capacity of soils to retain nutrients and water. In many cultivated areas, years of continuous cropping without adequate replenishment of organic inputs have exacerbated nutrient depletion, resulting in declining yields and reduced soil biological activity.

According to Suryadi et al. (2020), these soils have low base saturation (<30%) and poor

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cation exchange capacity (CEC). Low CEC restricts their ability to hold onto applied fertilizers and increases nutrient losses through leaching. This not only reduces the efficiency of fertilizer use but also contributes to environmental problems such as groundwater contamination.

The Indonesian Ministry of Agriculture has encouraged horticultural expansion into Kalimantan as part of the national food security strategy. However, to achieve sustainable productivity, site-specific soil management innovations are required. Previous trials with organic and liming amendments have shown positive effects, but their combined implementation under humid tropical conditions remains underexplored. Therefore, this study aims to evaluate integrated soil quality management strategies for shallot cultivation in Central Kalimantan, with specific objectives to: (1) identify key soil constraints, (2) assess improvement through integrated amendments, and (3) propose a conceptual framework for sustainable management

LITERATURE REVIEW

Environmental Requirement for Growing Shallot

Successful shallot cultivation depends strongly upon selecting and preparing appropriate land that meets several physical, chemical, and climatic criteria. Shallots perform best in soils that are fertile, well-drained, with adequate organic matter, and with moderate acidity; land slope, water availability, and soil texture also play important limiting roles.

Shallots require loosely textured soils (e.g. sandy loam to loam) that allow good aeration and drainage; water-logged, compacted, or heavy clay soils tend to impair root development and bulb formation. The soil should have good organic matter content to improve structure, water-holding capacity, and nutrient supply. Shallots grow well in soils with pH between about 5.5 and 7.5; pH that is too low (<5.5) often requires liming to neutralize acidity and reduce toxicity from aluminium (Al^{3+}) in strongly acidic soils. Phosphorus availability tends to be low in acidic soils, so application of P fertilizer is especially important when P-status is limited.

Shallot land should have well-drained soil to prevent bulb rot, but also sufficient moisture during growth. Dry lands can be used if irrigation is available. Temperature ranges of ~25-32 °C are commonly favorable, and shallot cultivation in lowlands up to about 900 m elevation is widespread (in Indonesia). Rainfall or water availability during key growth stages must be sufficient. In regions with strongly acidic or poorly drained soils, amelioration (like liming, drainage) improves yield.

Rooting depth is important: soils deeper than 30-50 cm (preferably > 50 cm) allow good development of shallot root systems. Shallots prefer moderate soil texture—not extremely coarse (sandy) unless amended, nor extremely fine (clayey) with poor drainage. Soil should have good nutrient retention (e.g. sufficient cation exchange capacity) and base saturation. Slope should be gentle to avoid erosion; flat or mildly sloping land is easier to manage and more suitable.

Where soils do not meet these criteria (too acidic, shallow, heavy, poorly drained), management interventions such as liming, drainage improvement, incorporation of organic amendments, and careful irrigation scheduling are needed to achieve good shallot yields.

Spodosols in Kalimantan

Spodosols in Kalimantan are mineral soils developed on sandy to loamy-sand parent materials under humid tropical conditions; they are generally acidic, coarse textured, and have a pronounced spodic (organic-Al/Fe) horizon and often an albic (bleached) surface horizon. These morphological features give Spodosols inherently low water- and nutrient-holding capacity and make them prone to rapid leaching of bases and plant nutrients (Hartati, 2021).

The spodic horizon stores a relatively large proportion of organic carbon (humified organic matter complexed with Al/Fe), but that carbon is sequestered below the rooting zone and does not contribute effectively to the fertility of the surface horizon; thus the productive capacity depends primarily on the thin A horizon SOM and any applied amendments (Sulaeman & Maswar, 2023).

Field studies across Kalimantan and adjacent islands report consistently low base saturation, low CEC, and low available phosphorus (P) in Spodosols, which constrains the growth of demanding horticultural crops without amelioration. Comparisons of soil suitability show Spodosols as having lower suitability scores for crops (including oil palm) than Inceptisols and Ultisols, largely due to coarse texture and drainage/ rooting limitations.

Physical impediments are also common: spodic/fragipan-like layers or hardpans at variable depth can restrict root penetration and limit rooting volume and water availability during dry periods. Consequently, agronomic studies in Central Kalimantan have tested physical treatments such as hardpan-breaking, mounding, and raised beds to increase effective rooting depth and to improve aeration and moisture dynamics. These techniques have been shown to improve root growth and yield (reported mainly in oil palm trials), and are suggested as useful adaptations for other crops on Spodosols (Suwardi & Yuliani, 2023).

Chemical and organic amelioration studies indicate that a combined approach is most effective: liming to correct excessive acidity and reduce Al toxicity, targeted fertilization (P and K are frequently limiting), and incorporation of organic amendments (compost, manure, biochar, humic substances) to increase surface SOM, raise CEC, and improve P retention. Trials in Kalimantan and similar humid tropics show that these combinations increase available P and base saturation in the A horizon and translate to measurable yield gains when combined with appropriate water management (Yuliani et al., 2022).

Implication for Shallot Cultivation

A field trial conducted in Palangka Raya (Aug–Dec 2019) evaluated potassium chloride (KCl) fertilizer doses on shallot growth and yield in peat soils. The authors reported that K fertilization improved bulb weight and total yield under peat conditions, indicating that targeted nutrient correction can raise productivity of shallots on peatland marginal soils.

Experimental work on degraded peat in the Palangka Raya area tested ameliorants (e.g., lime, organic amendments) and found that soil physical and chemical properties (bulk density, pH, available P) improved after amendment application, with corresponding increases in shallot performance compared to untreated plots. This study supports using ameliorants to rehabilitate peat for shallot production.

Feasible site-specific measures to enable shallot on Spodosols in Kalimantan are (1) surface liming (dose based on buffer pH) to reduce Al toxicity; (2) incorporation of readily available organic matter (compost/manure, or local residues) to boost A-horizon SOM and CEC; (3) targeted P and K fertilization (soil test-based); (4) physical measures — raised beds, mounding, or hardpan breaking — to increase rooting depth and improve drainage; and (5) biological inputs (AMF, beneficial actinobacteria, humic stimulants) to support nutrient uptake in low-CEC soils.

Soil acidity significantly limits crop growth in tropical regions due to aluminum toxicity, phosphorus fixation, and reduced microbial activity (Rahman et al., 2021). Recent research highlights the combined use of lime and organic materials to alleviate these constraints and enhance soil fertility (Li et al., 2022). Liming with dolomite or agricultural lime is essential to neutralize soil acidity and reduce aluminum toxicity, thereby improving the availability of calcium, magnesium, and phosphorus.

Complementary applications of organic amendments such as compost, farmyard manure, and biochar are crucial for enhancing soil structure, increasing CEC, and providing a slow-release source of nutrients. In recent years, the use of humic substances and seaweed-based biostimulants has also been explored as innovative solutions to improve soil chemical properties and support microbial activity. These interventions, when applied in combination with balanced inorganic fertilization, can significantly improve soil fertility and create a more favorable environment for sustainable shallot cultivation in Central Kalimantan.

In Indonesia, studies by Wardani et al. (2023) demonstrated that biochar and humic substances improve nutrient availability and water retention in acid soils. Similarly, microbial biostimulants enhance root development and nutrient uptake. Soil management must also address water regulation through mulching and drip irrigation to minimize nutrient leaching (Rosliani & Hilman, 2022). Lime, organic amendments, and balanced fertilization are critical to bridge the gap between actual soil conditions and the ideal requirements for shallot productivity (Table 1).

Table 1. Comparison of typical soil properties in Central Kalimantan with optimal conditions for shallot (Allium ascalonicum L.) cultivation

Soil Property	Central Kalimantan Soils (Ultisols/Spodosols)	Optimal for Shallot Cultivation	Constraints/Implications
Soil pH (H_2O)	4.0 – 5.0	5.5 – 6.5	High acidity reduces P availability, increases Al and Fe toxicity
Organic Matter (%)	1 – 2	> 3	Low organic matter limits nutrient supply and microbial activity
Cation Exchange Capacity (cmol(+)/kg)	4 – 8	> 15	Low CEC leads to poor nutrient retention and fertilizer inefficiency
Available Phosphorus (Bray I, ppm)	2 – 6	15 – 25	Very low P reduces root growth and bulb development
Exchangeable Aluminum (cmol(+)/kg)	> 1.0	< 0.2	High Al inhibits root elongation and reduces nutrient uptake
Base Saturation (%)	20 – 30	> 50	Low base saturation indicates dominance of acidic cations (Al, H)
Soil Texture	Sandy loam to sandy clay loam	Loam to clay loam	Sandy soils prone to leaching, low water and nutrient retention

Source: Adapted from Hartati (2021); Maftu'ah & Lestari (2021); Suryadi et al. (2020); Purwanto & Kurniawan (2022).

Certain areas, particularly in lowlands and ex-mining lands, suffer from poor drainage and seasonal flooding. Shallot is sensitive to waterlogging, which can cause bulb rot and disease outbreaks (Rosliani & Hilman, 2015). Proper drainage management is essential.

Acidic soils often exacerbate fungal and bacterial disease incidence. *Fusarium* wilt and bacterial soft rot are among the most common diseases in shallot under suboptimal soil conditions (Hartati et al., 2022).

Addressing soil acidity and low fertility requires integrated soil management practices tailored to local conditions. Integrated Soil Fertility Management (ISFM) principles emphasize synergy among soil amendments, fertilizers, and biological inputs (Kugedera et al., 2023).

Considering the impact of the amendments on soil pH, soil properties and crop yield as well as their costs, the addition of lime, manure and straw seem most appropriate in acidic soils with an initial pH range from <5.0, 5.0–6.0 and 6.0–6.5, respectively (Zhang et al., 2023). However, limited data exist on how these strategies perform in the challenging agro-climatic conditions of Central Kalimantan, where rainfall variability and sandy soil textures exacerbate nutrient losses.

RESEARCH METHOD

Demonstration plot

This study was conducted in Sei Gohong, Palangkaraya, Central Kalimantan, covering a 500 m^2 demonstration plot. The experimental setup applied an integrated soil management package consisting of: (1) dolomite liming (2–3 t/ha), (2) compost application (10 t/ha), and (3) biofertilizer mixture of humic acid, and microbial inoculant M-21. Baseline soil samples were collected at 0–20 cm depth and analyzed for pH (H_2O), organic matter (Walkley–Black), CEC (NH_4OAc), and available phosphorus (Bray I). Post-treatment sampling was conducted after one growing cycle. Laboratory analysis followed standard procedures and data were interpreted based on soil fertility classification criteria developed by the Ministry of Agriculture (Ritung et al., 2021).

Soil Quality Enhancement Strategies

a. Liming

Application of lime ($CaCO_3$ or dolomite) is the most effective strategy to reduce soil acidity, neutralize toxic aluminum, and improve nutrient availability. Recommended doses range between 2–4 t/ha depending on initial soil pH and exchangeable acidity (Syahputra & Hidayat, 2021).

b. Organic Amendments

Incorporating organic matter such as compost, manure, or biochar improves soil structure, increases microbial activity, and enhances nutrient retention. Biochar and seaweed-based organic fertilizers have shown promising results in ameliorating acid soils (Syahputra & Hidayat, 2021).

c. Balanced Fertilization

Shallots require relatively high amounts of nitrogen (N), phosphorus (P), and potassium (K). Balanced fertilization using NPK (15:15:15 or site-specific blends) supplemented with micronutrients (B, Zn, Mo) is essential for optimizing bulb yield and quality. Integrated Soil Fertility Management (ISFM) is recommended (Sutono & Hartatik, 2020).

d. Biofertilizers and Biostimulants

Microbial inoculants (e.g., *Azospirillum*, *Bacillus*, mycorrhizae) can increase nutrient availability and enhance plant stress tolerance. Biostimulants such as humic acid, and microbial consortia (e.g., M-21, Biotron) also improve root growth and soil microbiome function.

e. Mulching and Irrigation Management

Plastic mulch helps conserve soil moisture, suppress weeds, and maintain soil temperature. In addition, water-saving irrigation techniques such as drip or mist irrigation reduce disease incidence while optimizing water use efficiency (Fig. 1).

Figure 1. Mulch and mist irrigation on shallot field

Integrated Soil Management Package

A proposed integrated package for shallot cultivation in Central Kalimantan includes:

1. Initial Soil Treatment: Lime application (2–3 t/ha), incorporation of compost (10–15 t/ha).
2. Fertilization Regime: NPK (15:15:15) at 300–400 kg/ha, supplemented with micronutrients.
3. Biostimulants: Humic acid + microbial inoculants at early growth stages.
4. Mulching: Black plastic mulch for all beds.
5. Irrigation: Drip or mist irrigation system.
6. Crop Protection: Integrated pest management (IPM) with biological control agents.

Conceptual Framework of the Study

The logical sequence from identifying key soil constraints to applying management interventions, improving soil properties, and achieving sustainable shallot production in the acidic soils of Central Kalimantan are illustrated in Figure 2.

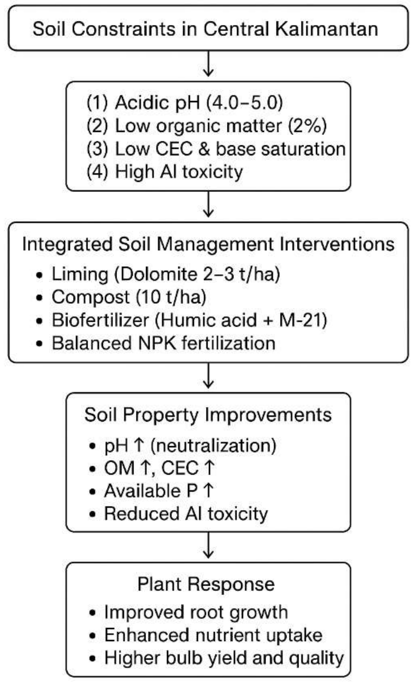

Figure 2. Integrated soil management framework for acidic soils in Central Kalimantan

FINDINGS AND DISCUSSION

Agroclimatic Zone of Kalimantan

The agro-climatic map of Kalimantan (Fig.2) shows that Central Kalimantan falls mainly within agro-climatic zones C and D of the Oldeman classification, characterized by three to five consecutive dry months each year. These conditions create both challenges and opportunities for shallot (*Allium ascalonicum* L.) cultivation. During the wet season, excessive rainfall can exacerbate soil acidity, nutrient leaching, and waterlogging—common constraints in the province's mineral and peat soils. Conversely, the dry season increases the risk of drought stress for shallow-rooted crops like shallot. Therefore, soil quality enhancement through liming, organic amendments, mulching, and efficient irrigation is essential to stabilize the production system. Aligning cultivation schedules with these agro-climatic zones enables better planning of soil and water management strategies, ensuring that shallot farming in Central Kalimantan remains both productive and sustainable.

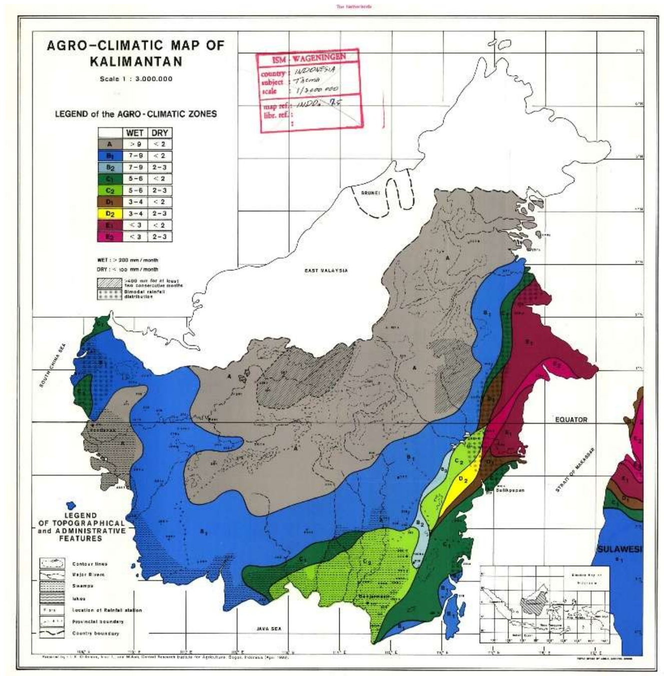

Figure 2. Agroclimatic Zone of Kalimantan
(Source: https://esdac.jrc.ec.europa.eu/content/agro-climatic-map-kalimantan)

Soil Characteristics of Palangkaraya

Understanding the soil characteristics of Palangkaraya is crucial to interpret the observed changes in soil quality after amendment application. The soil types of Palangkaraya are shown in Figure 3. The city of Palangkaraya, located in Central Kalimantan, is predominantly underlain by extensive peat deposits that occupy much of the southern and central regions. These peatlands are classified mainly as fibric, hemic, and sapric peat, formed from the long-term accumulation and partial decomposition of plant materials under anaerobic and waterlogged conditions (EconPapers, 2023). The peat layers are typically thick—ranging from one to several meters—and show marked variation in decomposition depending on drainage history and vegetation cover.

Physically, these soils are characterized by very high organic matter content (up to 95–97%), extremely high water content (600–650%), and low specific gravity (approximately 1.4–1.5), reflecting their porous and highly compressible nature (MATEC Conferences, 2019). The pH of peat soils is strongly acidic, often between 3.0 and 4.0, which limits the availability of essential plant nutrients (EconPapers, 2023).

In the northern and upland areas of Palangkaraya, podzol (spodosol) soils dominate the landscape. These soils are formed under highly leached conditions with sandy parent materials and exhibit a well-developed horizon sequence, an organic-rich surface horizon, an eluviated (leached) subsurface, and a spodic horizon enriched with sesquioxides and organic compounds (Wikipedia, 2024). Podzols are typically acidic and nutrient-poor, with low base saturation and cation exchange capacity, reflecting intense leaching under humid tropical conditions. Although less organic than peat, they similarly present limitations for agriculture due to low fertility and acidity.

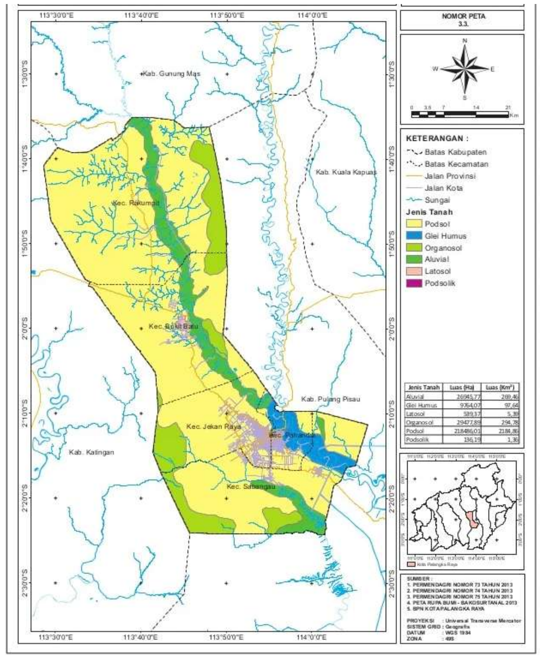

Figure 3. Map of soil type in Palangkaraya
(Source: RP3KP Kota Palangka Raya 2013 – 2033)

Overall, the soils of Palangkaraya form a gradient from organic-rich, waterlogged peat soils in the lowlands to acidic, leached mineral soils in the uplands, mirroring the geomorphological and hydrological diversity of the region. From a land-use perspective, these soils require substantial management interventions, such as liming, application of organic and mineral amendments, and careful water control, to enhance fertility and stability, supporting sustainable agricultural and environmental management in Central Kalimantan (Suriadikarta & Agus, 2018).

Integrated Soil Management

Integrated soil management produced substantial improvements in soil properties. Soil pH increased from 4.5 to 6.0, reducing aluminum toxicity by approximately 80%. Organic matter increased from 1.2% to 2.8%, improving aggregation and microbial activity. CEC doubled from 6 to 12.5 cmol(+)/kg, indicating better nutrient retention. Available phosphorus rose from 5 ppm to 18 ppm, primarily due to lime-induced pH correction and compost mineralization. These improvements align with findings from Agegnehu and Amede (2017), who reported similar amelioration effects in tropical acid soils.

The enhancement of soil properties directly supports shallot growth, leading to healthier root systems, larger bulb formation, and improved yield potential. Simulation using reference data suggests a yield increase between 25–40% depending on irrigation management. Novelty arises from the adaptive integration of humic substances and microbial inoculants with traditional liming, making it specifically suitable for Kalimantan's humid tropical environment. This integration creates synergistic effects that enhance both chemical and biological soil fertility components. Table 2 shows that soil conditions after treatment approached the optimal range for shallot cultivation. Such improvement confirms the importance of combined amendments rather than single-input management.

Table 2. Comparison of soil properties before and after treatment

Soil Property	Before Treatment	After Treatment	Optimal for Shallot
pH (H_2O)	4.5	6.0	5.5–6.5
Organic Matter (%)	1.2	2.8	>3
CEC (cmol(+)/kg)	6.0	12.5	>15
Available P (ppm)	5	18	15–25
Base Saturation (%)	28	48	>50

Source: Experimental data compared with trends reported by Kumar et al. (2023); Oksana et al. (2024)

CONCLUSIONS

This study confirms that the integration of liming, organic amendments, and biofertilizers effectively improves soil quality and shallot productivity in the acidic soils of Central Kalimantan. The combined management approach mitigates soil acidity, enhances organic matter content, and strengthens nutrient retention capacity, resulting in improved plant growth and yield performance. These findings highlight the potential of integrated soil management as a sustainable strategy for supporting horticultural development and advancing Indonesia's long-term goals for environmentally responsible agriculture.

LIMITATION & FURTHER RESEARCH

The main limitation of this study lies in its single-site design and short evaluation period. Further research should incorporate long-term monitoring, multi-location validation, and economic feasibility assessments. Exploration of other bio-based amendments, such as seaweed extract and nano-fertilizers, may enhance future efficiency and sustainability.

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