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**Review Articles**

# Site-specific nutrient management in rice (*Oryza sativa*): Status and prospect–A review

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ABSTRACT

Site-specific nutrient management (SSNM) plays a vital role in increasing crop profitability, maintaining soil health and reducing environmental pollution. Field experiments and demonstrations conducted across southeast (SE) Asia were conducted during 2020–21 at ICAR-Indian Agricultural Research Institute, New Delhi and observed that SSNM includes various nutrient management practices and each practice have a positive impact on fulfilling its vital role. After a thorough study, this review reflects that fertilizer recommendations based on targeted yield concept were more balanced, profitable and helpful in controlling soil nutrient mining and essential for sustainable crop production. Establishment of an attainable yield target, based on location, season, climate, rice cultivar and crop management ensures effective use of existing indigenous nutrients such as from soil, organic amendments, crop residue, manure and irrigation water and application of fertilizer to dynamically fill the deficit between crop needs and indigenous supply and to maintain soil fertility. Moreover, use of nitrification inhibitor, deep placement of nitrogen (N) and NPK fertilizers reduces the loss of N fertilizers up to 20% and increases rice yield up to 10%. The leaf colour charts (LCC), chlorophyll meter or SPAD are inexpensive need based tools for fertilizer N management that can reduce the excessive application of N (10–50%). Optical sensor-based nitrogen management is an alternative to LCC and SPAD that can quickly and reliably monitor N requirements of rice. On the other hand, the dissemination of SSNM through LCC, SPAD, QUEFT models, optical sensor etc., requires training of researchers, local extension workers, fertilizer retailers, and farmer leaders on techniques and guidelines for enabling rice farmers. Therefore, a simple nutrient decision support tool, Nutrient Expert® (NE) is useful to develop strategies to manage fertilizer N, P and K tailored to farmer's field or growing environment. However, comparative evaluation of different SSNM approach is essential for location wise fertilizer prescription for increasing crop profitability, soil health and environmental safety.

**Keywords**: Leaf color chart (LCC), Nutrient Expert® (NE), Optical Sensor, QUEFT, SPAD, SSNM

Rice (*Oryza sativa* L.) is one of the most important staple foods for more than half of the world's population and influences the livelihoods and economies of several billion people. In 2018, the world paddy production reached a new high of 769.9 million tonnes (MT) (510.6 MT, milled basis) (FAO 2018). Asia regaining momentum of paddy planting and representing 90% of global rice production followed by Latin America and Sub-Saharan Africa producing about 25 and 19 MT respectively. Rice has been feeding Asia's population for over 4000 years and is the staple food of about more than 557 million people. Currently, the production of rice is dominated by Asian countries where China tops on the list of top 10 rice producing nations with a production of 209.61 MT. The latest data puts India in the second position (177.65 MT); Indonesia, Bangladesh and Vietnam have secured a place among the top five rice producing countries. However, Japan (10.89 MT) and Brazil (10.53 MT) are on 11$^{th}$ and 12$^{th}$ position respectively (FAO 2019). Rice output in Asia should therefore, grow at a minimum of 1.2% per annum to meet the growing demand. The global average productivity of irrigated rice is 5 t/ha, but national, regional and seasonal yield averages vary widely. In the tropics, skilled rice farmers achieve rice yields of 7–8 t/ha in the dry season and 5–6 t/ha in the wet season because cloud cover reduces the amount of solar radiation.

The demand for N, $P_2O_5$ and $K_2O$ is projected to grow annually on an average by 1.5, 2.2 and 2.4% respectively from 2015 to 2020. The total world fertilizer consumption reached 181.9 MT of nutrients in 2014-2014/15, of which 102.5, 45.9 and 33.5 MT are N, $P_2O_5$, and $K_2O$ respectively. Out of this total, 89.6 MT are estimated to have been applied to cereals, i.e. slightly less than half (49.3%) of world fertilizer use. Of the top three cereals, maize was the greatest contributor to world fertilizer consumption (16.2%), followed by wheat (15.3%) and rice (13.7%). It is estimated that 57.3 MT of N were applied to cereals in 2014-2015,

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representing 55.9% of world fertilizer N consumption. However, application of the organic sources, poultry manure (2.5 t/ha) was found to be most profitable to supplement up to 50% NPK and sustaining soil fertility (Baishya *et al.* 2016b) Therefore, intensive rice production and future rice demands will require knowledge intensive strategies for the efficient use of all inputs, including fertilizer nutrients.

*Site-specific nutrient management (SSNM)*

SSNM is a plant-based approach that enables farmers to optimally supply their crop with essential nutrients. It was estimated that rice yields in Asia must increase by about 14% from 2000–2010 and by 25% from 2000–2020. Assuming that the average yields of irrigated rice must rise from 5.3 t/ha in 1998 to 6.5–7.0 t/ha in 2020. Therefore, the project monitoring research began at five sites with a tropical climate and a rice-rice cropping system (Nueva Ecija, Philippines; Tamil Nadu, India; Cantho Province, Vietnam; Suphan Buri, Thailand; West Java, Indonesia) to identify the major constraints to productivity. The work expanded to three new sites with subtropical climate (Zhejiang Province, China; Red River Delta, Vietnam; Uttar Pradesh, India) and broadened to include studies on soil microbial characteristics and nutrients such as phosphorus (P) and potassium (K) in attrition to the quantification of N-use efficiency, understanding of soil organic matter chemistry and monitoring of the indigenous nutrient supply as a measure of soil quality (Table 1). The results of the monitoring work led to the development of a new approach for SSNM.

*Approaches and refinement of SSNM*

Soil-based approaches attempted for fertilizer recommendations to the soil-nutrient supplying capacity of specific fields, as determined through soil test analyses. Rice, unlike other main food crops, is typically grown in submerged soils where soil submergence alters biological and chemical processes that influence the release of plant available nutrients. Soil test analyses often do not effectively account for these effects of soil submergence on soil nutrient supply and the needs of rice for supplemental nutrients. SSNM for rice developed in Asia is a plant-based approach for feeding rice with nutrients as and when needed. The SSNM approach was developed across diverse irrigated rice growing environments in Asia where 90% of the world's rice is produced as reported by Buresh (2007). The concept for SSNM was then evaluated and refined from 1997 to 2000 on about 200 irrigated rice farms in eight major rice growing areas across six countries in Asia and the initial SSNM concept was systematically transformed to provide farmers and extension workers with simplified plant-need-based management of N, P and K during 2001 to 2004. The countries involved were Bangladesh, China, India, Indonesia, Myanmar, Thailand, Philippines and Vietnam.

*Nutrient omission plot technique/ Soil based approaches*

In this approach, the fertilizer (N, P and K) required by a crop can be estimated from the anticipated crop response to the respective fertilizer, which is the difference between a yield target and yield without that fertilizer. For example,

*Yield response to fertilizer N = Yield target – N-limited yield*

The yield target is the rice grain yield attainable by farmers with good crop and nutrient management and average climatic conditions for a given location. The N-limited yield can be determined with the nutrient omission plot technique from the grain yield for a crop not fertilized

Table 1 Significant research highlights on nitrogen management: QUEFT model, LCC, chlorophyll meter (SPAD) and optical sensor based nitrogen management in India, Vietnam and China

| Finding | Location | References |
|---|---|---|
| Saving 33.3% N with the agronomic N use efficiency 58.5% and N-recovery efficiency 32.2% in rice can be achieved with the use of SPAD chlorophyll meter (SPAD) over conventional practices. | Bihar, India | Ghosh *et al.* (2020b) |
| The net income worth ₹ 29254/ha and B:C ratio (1.84) was recorded the highest with SSNM on LCC-4 which was closely followed by 100% RDF+Vigore @ 625 g/ha. | UP, India | Kumar *et al.* (2019) |
| The grain yield of rice, N uptake and fertilizer N use efficiency measured with N management following threshold leaf greenness of 0.5 units less than LCCN rich were at par with the SPAD meter-based 90% sufficiency index approach and were better than the blanket fertilizer recommendation in the region. The LCC-based dynamic threshold greenness strategy holds promise to efficiently manage fertilizer N rice as it can effectively take care of variations in the rice cultivars, locations and seasons. | Punjab, India | Singh *et al.* (2016) |
| GreenSeeker-based precision management and chlorophyll meter-based site-specific N management increased the partial factor productivity of farmers by 48 and 65%, respectively, without significant change in grain yield. The crop sensor-based N management strategy can therefore, improve N-use efficiency of rice. | China | Yao *et al.* (2012) |
| Application of N fertilizer whenever leaf greenness was less than shade 4 on the LCC (the critical LCC value) produced rice grain yields at par with a blanket recommendation of applying 120 kg N/ha in three equal splits in different years, but it resulted in an average saving of 26% fertilizer N across villages and seasons. | India | Singh *et al.* (2007) |

with N but fertilized with other nutrients to ensure they do not limit yield. The yield target can be estimated from the grain yield in a fully fertilized plot with no nutrient limitations and good management. Surveys conducted during 2003-04 in the Upper-Gangetic Plain Zone, India revealed that SSNM considers the indigenous nutrient supply of the soil and productivity targets as a strategy to provide sustained high yields on one hand and assure restoration of soil fertility on the other. These nutrients, in order, were applied as urea, muriate of potash, gypsum, zinc sulfate, manganese sulfate and sodium tetra borate. This experimental result revealed that fertilizer application according to the SSNM schedule for treatment $N_{170}$ $P_{30}$ K $_{120}$ Zn $_{7}$ $Mn_{17}$ and $B_{0.6}$ resulted in the highest rice grain yield of 9.95 t/ha, whereas farmer practice (FP) (N $_{180}$ $P_{60}$) produced the lowest yield of 7.29 t/ha. Foliar application of 2% zinc sulphate along with recommended doses of fertilizers has also shown increase in the yield and quality of rice (Baishya *et al.* 2019).

An experiment conducted by Das *et al.* (2009) highlighted that the highest grain yield in rice (5.83 t/ha) was observed in the treatment where NPK was applied at 64:51:50 kg/ha to achieve the target yield of 6 t/ha based on QUEFTS. Baishya *et al.* (2016a) advocated that application of FYM (2.5 t/ha) + crop residue (2.5 t/ha) + lime (400 kg/ha) recorded highest rice grain and straw yield in acid soils. Sarkar *et al.* (2018) suggested that fertilizer recommendations based on targeted yield concept were more balanced, profitable and helpful in controlling soil nutrient mining and essential for sustainable crop production. The application of lime 400 kg/ha in acid soils was also found to be more effective for increasing rice production in acid soils (Baishya *et al.* 2015). Fertilizer adjustment equations were developed for upland rice using the basic data, which showed that N, P and K requirement to produce 1 q of rice grain was 2.75, 0.20 and 3.53 kg, respectively (Sarkar *et al.* 2016). On the other hand, many farmers often use uniform rates of N fertilizers based on expected yields (yield goal) that could be inconsistent from field-to-field and year-to-year depending on factors that are difficult to predict prior to fertilizer application. In general, farmers apply fertilizer N much higher than the blanket recommendations to ensure high crop yields. Therefore, the following approaches were developed for the effective management of nitrogen.

*Urease and nitrification inhibitors*: The use of urease inhibitors to reduce $NH_3$ volatilization from urea, hydrolysis has emerged as an effective strategy to increase N-use efficiency of urea based N products in rice. More than 14000 compounds or mixtures of compounds with a wide range of characteristics have been tested and many patented as urease inhibitors, but the compound N-(*n*-butyl) thio-phosphoric triamide (NBPT) has been reported to significantly minimize $NH_3$ volatilization losses from urea. The urease inhibitors available so far can prevent urea hydrolysis for at most 1 or 2 weeks, during which the fertilizer should ideally be incorporated into the soil by water (rain or irrigation) or mechanical methods (Chien *et al.* 2009). Therefore, the application of nitrification inhibitors needs to be coordinated with drainage management of floodwater and/or permeability of soils.

*Deep placement of N fertilizers*: Early studies showed that incorporating N fertilizer at 10–12 cm depth reduced $NH_3$ volatilization losses to just 1% compared to losses of 20% when N fertilizer was surface applied. The techniques have been developed to place fertilizer N in the soil: (i) Urea Super Granule (USG) hand placement; and (ii) urea band mechanical injection. USG or briquettes are made by compressing prilled or granular urea in small machines with indented pocket rollers to produce individual briquettes varying in weight from 0.9–2.7 g. Within a week after transplanting rice, the briquettes are inserted into the puddled soil by hand, being placed to a depth of 7–10 cm in the middle of alternating squares of four hills of rice. Recently, mechanical applicators have been developed for USG application at adjustable row spacing (Hoque *et al.* 2013) and these are being perfected to avoid the labour-intensive practice of placing USG with hand. Several studies have shown yield increases, reduced losses of N and increased fertilizer N use efficiency from deep placement of USG (Huda *et al.* 2016). As evident from a large number of research reports showing better performance of USG than the split application of broadcast urea, USG is increasingly being used by farmers in Asia. Sarker *et al.* (2015) reported that deep placement of NPK briquettes resulted in 4–10% higher rice yield and nutrient savings of 20–35% N, 18% P and 17–24% K over the recommended practice of NPK incorporation. The one-time deeply placed fertilizer application synchronous with sowing by precision hill-drilling machine will also lead to improved resource and energy management in rice (Singh *et al.* 2016).

*Leaf Color Chart (LCC)*: The leaf color chart (LCC) is an inexpensive and simple tool for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status. Field experiments conducted by Singh *et al.* (2007) at 100 on-farm locations to study N management in irrigated rice (June–October) using the LCC reveals that N-use efficiency can be significantly improved by reducing the amount of fertilizer N applied without sacrificing grain yield of irrigated rice through need-based N management using LCC in the Indo-Gangetic plains of North-western India. The critical LCC value of 4 with 20 kg N/ha as basal dose at transplanting can be used for all the inbred lines presently popular with the farmers in Indo-Gangetic plains. They also reported that basal application of fertilizer N can be avoided if yields without applying fertilizer N in a field are more than 3 t/ha. Peng *et al.* (2010) after one decade of research on SSNM in China and other Asian rice growing countries, reported that leaf N is below the low level of the SPAD or LCC thresholds, N rate will be increased by 10 kg/ha; when leaf N is greater than the upper level of the SPAD or leaf colour chart thresholds, it will be decreased by 10 kg/ha. No adjustment in the N rate is needed when leaf N is within the thresholds. At heading, N is applied only if leaf N is below the SPAD or LCC thresholds. Kumar *et al.* (2019) reported that net income worth ₹ 29254/ha and B:C ratio (1.84) was recorded the highest with SSNM on LCC-4. However, the SPAD and LCC thresholds vary with varieties, which need to be determined experimentally. *Japonica* generally requires higher thresholds than *indica*.

*Chlorophyll meters (SPAD)*: Chlorophyll meters instantly provide an estimate of leaf N status as chlorophyll content by clamping the unlocked leafy tissue in the meter. It uses two LEDs (light-emitting diodes) which emit red light with a peak wavelength of 650 nm and infrared radiation with a peak wavelength of 940 nm. Fertilizer N applications are necessary below this threshold value to avoid yield loss. In South India, SPAD value of 35 was found to be the appropriate threshold value for guiding need-based N management in transplanted rice. Nevertheless, the SPAD meter threshold value of 35 is not universal and may vary in different rice growing environments (Balasubramanian *et al.* 1999). In Northern India, SPAD value 37.5 was found to be critical for rice. Hussain *et al.* (2003) also found that a critical SPAD value of 37.5 was appropriate for guiding needs-based N top dressing in rice in Pakistan. Different threshold SPAD values may have to be used for different varietal groups as well (Huang *et al.* 2008).

*Sufficiency index value approach*

Sufficiency index is defined as the SPAD value of the test plot expressed as a percentage of the SPAD value of an over-fertilized reference plot or strip. This approach has the advantage of being self-calibrating for different soils, seasons and cultivars because SPAD threshold values are established dynamically with respect to an over-fertilized reference plot. Singh *et al.* (2016) observed that following the criteria of 90% sufficiency, 50 kg N/ha less fertilizer was used in comparison to fixed-time fixed-dose application of 120 kg N/ha with no reduction in the grain yield. Maiti *et al.* (2004) found that need-based fertilizer N application guided by a critical SPAD value of 37 rather than 35 resulted in high yields and less fertilizer N application to the tune of 27.5–45.5 kg N/ha as compared to the blanket dose of 150 kg N/ha.

*Chlorophyll meter (SPAD) vs LCC*: The fixed threshold greenness varies with regions, rice cultivars and seasons (Singh *et al.* 2016). Dynamic threshold greenness is defined as 90% of the SPAD meter reading of leaves in an N rich or over the fertilized strip. The grain yield of rice, N uptake and fertilizer N use efficiency measured with N management following threshold leaf greenness of 0.5 units less than LCC N rich were at par with the SPAD meter-based 90% sufficiency index approach and were better than the blanket fertilizer recommendation in the region.. Ghosh *et al.* (2020a) evaluated three SPAD thresholds (34, 36 and 38 in rice and 38, 40 and42 in wheat) using three N levels (15, 25 and 35 kg N/ha) in split were incorporated as real-time N management (RTNM), one fixed-time N management (FTNM), farmers' fertilizer practice (FFP) and control (no fertilizer) in wet and dry seasons for rice and wheat, respectively. Topdressing with 25 kg N/ha at medium SPAD (S36 in rice and S40 in wheat) increased soil N availability, leaf N content and grain yield of rice (5.22 t/ha) and wheat (4.48 t/ha) over the grain yield recorded under a low rate of N topdressing at low SPAD. While saving 33.3% N in rice and 18.8% N in wheat, the agronomic N use efficiency (58.5% in both rice and wheat) and nitrogen recovery efficiency (32.2% in rice and 15.1% in wheat) can be increased when compared with conventional FTNM. The SPAD-based management strategy showed great promise in the efficient management of N fertilizer and they estimated the optimal SPAD threshold for rice and wheat as 37.5 and 41.8, respectively. Ghosh *et al.* (2020b) also observed that topdressing of 25 kg N/ha at SPAD 36 and 40 (S36 and S40) for rice and wheat respectively, reduced the N requirement by an average of 26.5% (33.3% in rice and 18.8% in wheat) over the fixed-time N management (FTNM) without reducing the grain yield. The 25 kg N/ha increased nutrient removal in the system having high agronomic N use efficiency (21.4) and N recovery efficiency (0.60) with the lower N requirement (62.5 kg N/ha) over the FTNM. This study suggests that using SPAD meter in rice–wheat system can cover the productive N management and profitability and can be dependably used in precision agriculture to manage the spatial variation in farmers' field.

*Optical sensor based nitrogen management*: Optical sensors measure visible and near-infrared (NIR) spectral response from plant canopies to detect the N stress. Spectral vegetation indices such as the normalized-difference vegetation index (NDVI) have proved useful for indirectly obtaining information such as photosynthetic efficiency, productivity potential and potential yield. A handheld GreenSeeker optical sensor unit has been used for site-specific N management in rice. Experiment conducted by Yao *et al.* (2012) in Heilongjiang Province, Northeast China reported that GreenSeeker-based precision N management strategy has several advantages compared with the SSNM-chlorophyll meter strategy. It adjusts the topdressing N application rate at stem elongation stage based on potential yield response to additional N application rather than a fixed rate of adjustment based on chlorophyll meter values. It uses a canopy sensor rather than a leaf sensor and thus is faster under field conditions. It is less influenced by environmental light conditions because the GreenSeeker sensor is an active sensor with its light source. This strategy adopts N rich plots as reference plots to minimize the influence of different varieties and other environmental factors. The GreenSeeker-based strategy also reduced N topdressing times as compared with the SSNM strategy used in this study and thus can save labour costs. Drones fitted with infrared, multispectral and hyperspectral sensors can analyse crop health and soil conditions precisely and accurately. NDVI data, in combination with other indexes such as the Crop-Water Stress Index (CWSI) and the Canopy-Chlorophyll Content Index (CCCI) in agricultural mapping tools can provide valuable insights into crop health (Sylvester 2018).

*Nutrient Expert® (NE)*: A simple nutrient decision support tool based on the principles and guidelines of SSNM, such as Nutrient Expert® (NE), will help crop advisors to develop strategies to manage fertilizer N, P and K tailored to a farmer's field or growing environment. The algorithms involved in NE are so meticulous that it captures the required information through logical questions and predicts the yield responses close to the actual yield responses (Pampolino *et al.* 2014). The NE estimated yield responses compared with that of actual yield responses showed 16% higher N response, 31% lower $P_2O_5$ response and 29% lower $K_2O$ response over the actual responses observed through omission plot techniques in different states of India. Other SSNM (STCR, LCC, SPAD and GS etc.) requires good understanding and motivation of the extension staff, different farmers or farmers-groups.

Extension agents still perceive SSNM is complex, requiring an understanding of concepts and methods outside their experience. SSNM on fertilizer application has not taken into account, other sources of nutrients such as farmyard manure, crop residues carried over and quality of water. NE estimates yield responses based on sound scientific principles even in the absence of soil testing and forms the basis for generating fertilizer recommendations (Satyanarayana *et al.* 2014). The digitized soil surveys and weather information can be linked with the farmer's data for use in decision-support tools. Farmers can gain much more benefit by sharing the data with their advisor partners. The information management helps today's farmers to put the right nutrient source on at the right rate at the right time in the right place with 4R nutrient management. In the near future, unmanned remote control drones and helicopters and on-the-ground robotics will become a part of site-specific precision agriculture. Results of the field evaluation of NE in Indonesia and Philippines demonstrated the ability of NE to increase farmer's yield and income across a range of climates, soil types and cropping systems (Pampolino *et al.* 2014). Mamuna *et al.* (2018) evaluated the performance of high yielding boro rice varieties with four fertilizer management options, viz. (i) use of Rice Crop Manager (RCM), (ii) Soil Test Based (STB) fertilizer application, (iii) BRRI Recommended Fertilizer (BRF) application and (iv) Farmers' Fertilizer Practice (FFP). They reported that fertilizer management practices and variety interacted significantly to influence yield components and yield of rice. However, the grain yield produced with RCM was comparable with that of BRF management. The RCM involved lower fertilizer cost than that of BRF and FFP. Hence, the gross return and profit of rice obtained from RCM was similar to that in BRF. The cost dominant analysis confirmed that RCM was economic and profitable fertilizer management practices in southern Bangladesh. Sharma *et al.* (2019) compared field-specific fertilizer recommendations from Nutrient Manger Rice (NMR) with uniform application of fertilizer provided by an existing blanket fertilizer recommendation for irrigated inbred rice (BFR) and farmer's fertilizer practices (FFP) in on-farm trials conducted in 74 irrigated rice fields across three growing seasons in the Cauvery Delta, Tamil Nadu, India. They observed the grain yield was 0.6–0.7 t/ha higher with NMR than FFP in two of the three seasons, even though total fertilizer cost was comparable or less with NMR. The NMR reduced fertilizer N and P rates and total fertilizer cost compared to BFR. Use of NMR rather than BFR also had less risk of financial loss for a farmer. The likelihood of financial loss with a switch from FFP to BFR averaged 31%. It was reduced to 18% with a switch from FFP to NMR. NMR facilitated the calculation of field-specific fertilizer N, P, and K management practices, which increased fertilizer use efficiency without loss in rice yield compared to a recommended uniform fertilizer management across fields.

*Aerial imagery and site maps*: The value of GPS, GIS and remote sensing technologies can help to develop a comprehensive crop and soil-nutrient management plan. Singh *et al.* (2016) used GIS based mapping and found that phosphorus use was sub-optimal in all the crops except in potato-based systems. Perret *et al.* (2018) used zoning maps to apply macro- and micro-elements according to soil deficiencies and crop needs. They reported that grain yield was 4.72 t/ha for the conventional fertilization and 5.62 t/ha for the optimized site-specific fertilization resulting in a production yield increase of 18.9%. The yield of the optimized fertilization was 42.6% higher than the Costa Rican average. A cost-benefit analysis was carried out indicating that the optimized site-specific fertilization resulted in gains of US$ 188/ha per rice cycle compared to conventional fertilization practices.

### *Conclusion*

The study indicated that the selection of appropriate SSNM plays a vital role in increasing crop productivity and profitability. However, comparative evaluation of all nutrient management practices like LCC, Chlorophyll meters (SPAD), Optical sensor based and nutrient expert's recommendation are essential for different locations across the country. The Nutrient Expert (NE) is also an effective tool to cater more poor and marginal farmers with eco-friendly nutrient management practices for increasing crop profitability and sustainable agriculture.

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