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Agronomic assessment of rice genotypes (*Oryza sativa*) under different levels of fertilizer application: A review

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ABSTRACT

The current rice production system, centered around the high-input green revolution methods, tends to favour affluent farmers, leaving lower-income farmers unable to fully embrace modern agricultural techniques due to soaring input prices. In India, shrinking cultivable land and a growing population have led to intensified agronomic practices like heavy chemical fertilizer usage mainly impacting soil health and crops productivity especially rice. This trend has discouraged poorer farmers from rice cultivation due to diminishing factor productivity and profitability amidst rising input expenses, posing significant concerns about sustainability and economic viability. In this context, the review aims to assess how rice (*Oryza sativa* L.) genotypes perform when exposed to varying levels of fertilizer application, providing valuable insights into their adaptability and potential for increased productivity and soil fertility. It was investigated how different fertilizer levels, specifically nitrogen, phosphorus, and potassium, affects important agronomic practices, yield-related parameters, and grain quality in various rice genotypes. A diverse set of genotypes represent a broad spectrum of genetic background and adaptation strategies, including those known for their efficiency in using nutrients. Highlighting how the robustness of certain genotypes under conditions with limited nutrients maintained satisfactory yields and grain quality. In contrast, some genotypes demonstrated superior performance under higher fertility conditions, resulting in significant yield increases, larger grain sizes, and improved nutritional profiles. These approaches optimize fertilizer application, reduce the environmental impacts associated with excessive nutrient use, and ultimately enhance overall rice production.

Keywords: B:C ratio, Fertilizer levels, Lowland rice, Rice genotypes, Tiller, Transplant

Rice (*Oryza sativa* L.) serving as a staple food for a significant portion of the world's population as it is a principal food crop accounts for ~60% of the world's energy consumption (Kumar *et al.* 2019) and ~70% of the daily calories globally by people in rural areas (Yogi *et al.* 2023). The annual need for rice cultivation is on the rise, with projections suggesting a demand of approximately 140 million metric tonnes by the year 2025 (Kumar *et al.* 2016, Singh *et al.* 2019). Despite significant research, there might still be gaps in understanding the specific genotype-fertilizer interactions, particularly under diverse environmental conditions, soil types, and regional variations (Kumar *et al.* 2019). Therefore, one critical aspect of rice production is understanding how different rice genotypes respond to varying fertility levels in the soil may be an attractive, cost-effective, safe approach for sustaining the rice productivity (Kumar *et al.* 2018). Efficient nutrient management during critical growth stages is essential to fulfill the crop's nutrient needs throughout the season, ultimately impacting yields (Sampath *et al.* 2017).

Nutrient uptake is intricate and interrelated; for instance, phosphorus (P) and potassium (K) improve nitrogen (N) uptake, resistance to abiotic stress (Marschner 2012). Genotype, environment, soil properties, and nutrient inputs collectively influence crop response (Kamal *et al.* 2015). Achieving optimal yield with fertilizer levels and combinations is crucial for enhancing nutrient use efficiency in rice cultivation (Metwally *et al.* 2011). In today's agricultural landscape, it has become essential to identify and introduce high-yielding genotypes. This enables us to conduct comprehensive evaluations of growth studies and their impact on grain production across various nutrient levels on paddy (Bahuguna *et al.* 2023). Rice varieties exhibit varying responses to different soil fertility conditions, highlight the importance of determining the ideal fertilizer levels needed for the optimal growth and development of these promising genotypes, ultimately leading to increased yield and improved quality (Kumar *et al.* 2020). This

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review aims to provide a comprehensive assessment of the agronomic performance of various rice genotypes under different fertility conditions. By examining the interactions between genotype and soil fertility, we can uncover valuable insights that contribute to the development of sustainable and high-yielding rice cultivation strategies. This review will root into studies that explore the impact of nutrient levels, fertilizer applications, and soil properties on rice growth, yield, and overall performance, shedding light on the best practices for optimizing rice production in diverse agroecological systems.

Role of NPK nutrients in rice

NPK, comprising Nitrogen (N), Phosphorus (P), and Potassium (K), is vital for rice cultivation. Nitrogen fuels leafy growth, ensuring lush foliage and robust tillering. Phosphorus supports root development, energy transfer, and reproductive structure formation, crucial for early root establishment and grain development (Harish *et al.* 2022). Potassium enhances plant health and resilience, improving disease resistance, regulating water uptake, and aiding drought tolerance. NPK is positively correlated with yield of crops and soil fertility (Chaudhary *et al.* 2019). Balanced NPK application is pivotal as excess nitrogen can hinder grain formation, while inadequate phosphorus or potassium can limit root growth and stress tolerance. Achieving the right NPK ratio is vital for maximizing rice yields, ensuring crop health, and meeting global food demands while promoting sustainable agriculture practices (Singh *et al.* 2017).

Nitrogen: Nitrogen is vital for plants, serving as a component in amino acids, nucleic acids, proteins and hormones, essential for plant growth (Wang and Schjoerring 2012). Furthermore, it holds a pivotal regulatory function in multiple biological processes such as carbon and amino acid metabolism, nucleic acid procedures, and protein synthesis (Cai *et al.* 2012). Nitrogen stands as the predominant mineral component in plant tissues, primarily obtained from the soil. However, an excess of nitrogen can lead to notable drooping of leaves (Garg *et al.* 2020), low nutrient use efficiency, yield stagnation and high environmental risk (Kumar *et al.* 2019). Many rice-growing regions are classified as nitrogen-deficient, responding well to nitrogen application due to differences in N dynamics (Kumar *et al.* 2020).

Phosphorus: Phosphorus plays a vital role in the growth of rice, especially in fostering root growth, root functions and the accumulation of dry matter (Guo *et al.* 2012). When phosphorus is applied as basal in lowland rice, it leads to improved total dry weight, increased leaf area and a greater no. of tillers (Watanabe *et al.* 2014). Phosphorus also supports root development, tillering, early flowering, and metabolic activities, especially in protein synthesis (Harish *et al.* 2022). Research has demonstrated that the inclusion of phosphorus results in an elevated count of productive tillers per hill, consequently enhancing yield (Khan *et al.* 2013).

Potassium: The demand for potassium (K) in rice crops has risen annually (Frageria 2015). Rice plants extract substantial amounts of potassium from the soil (Crusciol *et al.* 2016), which plays a vital role in various physiological and biochemical plant processes. K is involved in stomatal regulation, disease control and confers tolerance to drought, heat, and cold stress (Rowland *et al.* 2010). It is essential for root growth, plant vigour and lodging prevention.

Effect of NPK and genotypes on growth attributes of rice

In a study on hybrid rice, Mondal *et al.* (2013) advocates that the application of NPK fertilizer (125: 62.5: 62.5 kg/ha) substantially enhanced growth attributes of rice, viz. plant height, number of tillers/m^2, leaf area index (LAI), dry matter accumulation and crop growth rate (CGR) when compared to lower fertilizer rate of application. In a field study by Dey *et al.* (2014) on hybrid rice cultivation, five nitrogen levels (0, 60, 120, 180 and 240 kg/ha) were tested. The research indicated that 180 kg N/ha resulted in enhanced growth attributes such as plant height, the number of tillers/m^2 and dry matter accumulation. The study conducted by Kumar *et al.* (2014) on rice genotypes with different nitrogen levels indicated a significant differences in LAI, dry matter production and the number of tillers/hill, which increased with higher nitrogen levels. The highest dry matter yield and number of tillers/hill were recorded highest at 225 kg N/ha in tested hybrid PA6201 and PHB-71 over Rajavadlu. Pramanik and Bera (2013) noted that maximum plant height occurred consistently with a nitrogen dose of 200 kg/ha in hybrid rice 25-P-25. Nath *et al.* (2018) explored 7 rice hybrids (NDRH-2, SHP-O1, SHP-02, SHP-03, SHP-04, SHP-05 and SHP-06) with different (120: 60:60, 150: 75: 75 and 180: 90: 90 kg NPK/ha) fertility levels over years. SHP-04 exhibited exceptional traits, matching NDRH-02 in plant height and tillers. Paramasivan *et al.* (2018) reported that the application of 200:75:75 kg NPK/ha resulted in taller plant height (95.7 cm) and longer panicle length (27.2 cm) as compared to the control. Joshi *et al.* (2019) conducted a study on 6 rice genotypes and found that incremental doses of nitrogen, phosphorus, and potassium (150% RDF) significantly improved growth parameters, including plant height, no. of tillers, and panicles/m^2. Bahuguna *et al.* (2023) reported that when fertilized with 150% RDF (180:90:60 kg NPK/ha) genotypes IET-27263 and NDR-359 resulted in maximum growth parameters.

Effect of NPK and rice genotypes on yield and yield attributes of rice

Singh *et al.* (2013) conducted an extensive evaluation of rice genotypes, identifying PHB 71 as superior to NDR-359 in terms of yield attributes, grain production, economic viability, nutrient absorption and soil health. PHB 71 achieved remarkable grain and straw yields of 7219 and 8364 kg/ha, respectively. In a study on hybrid rice, Mondal *et al.* (2013) advocates that the number of panicles/m^2, panicle length, number of spikelets/panicle, number of grains/panicle and test weight has increased with application of NPK fertilizer (125: 62.5: 62.5 kg/ha) that led to higher grain productivity (7039 kg/ha). Dey *et al.*

(2014) on hybrid rice cultivation with 5 nitrogen levels (0, 60, 120, 180 and 240 kg/ha) found that 180 N/ha increased the yield attributing characters like number of panicles/m^2, panicle length, number of grains/panicle, percentage of filled grains and test weight that led to high crop productivity. The study conducted by Kumar *et al.* (2014) on rice genotypes with different nitrogen levels, observed that hybrid PA6201 and PHB-71 recorded 19.84%, 15.61% of yield advantage respectively over variety Rajavadlu at 225 kg N/ha and also interaction effect between rice cultivars and nitrogen levels on grain yield found to be significant. Srivastava *et al.* (2014) observed that applying 100% RDF with a ratio of 150:75:75 kg NPK/ha significantly enhanced various yield attributes such as effective tillers/m^2 (10.1%), filled grains/panicle (18.6%), test weight (11.0%), grain yield (19.0%) and straw yield (24.2%) compared to 50% RDF in rice variety PHB-71. In Hoang *et al.* (2015) study on PB53 rice, increasing nitrogen, phosphorus, and potassium (NPK) fertilizer doses resulted in higher grain yields, with the best performance observed at 120:100:100 kg/ha NPK. Kamal *et al.* (2015) examined two rice varieties and found that the 162:120:72 kg NPK/ha significantly improved yield and related traits compared to other NPK levels, with Leader-555 consistently outperforming PHB-71 across all NPK levels. With the objective to optimize the fertilizer doses of major nutrients, Murthy *et al.* (2015) conducted a field experiment and found that grain yield increased by 11.5% and 6.3% as the increase in N from 100% (120 kg/ha) to 125% and 150%, P and K doses from 100 to 125% (P from 60 to 75 and K from 40 to 50 kg/ha) in variety MTU 1010. Abdul *et al.* (2016) noted variable fertilizer responses among rice varieties, with Sadamota achieving the highest yield (3.84 t/ha) using 40, 15 and 24 kg NPK/ha. Jana *et al.* (2017) identified optimal rice genotypes with 105 kg/N ha, leading to superior yield attributes and the highest grain production, with Sampriti as the top-performing variety. Kumar *et al.* (2017) found that rice variety PAC-837 consistently outperformed others in grain and straw yield, achieving its highest grain. Kumar *et al.* (2017) assessed 4 rice varieties, viz. PR-115, DRRH-3, PAC-837 and PR-121 and 4 fertility levels, viz. control, 90: 45: 22.5, 120:60:30 and 150: 75: 37.5 kg/ha and found highest growth attributes and yield in PAC-837 with 120:60:30 kg/ha. Nath *et al.* (2018) explored rice varieties and fertility levels over years and found that SHP-04 exhibited exceptional traits, matching NDRH-02 in dry matter accumulation. Kharel *et al.* (2018) determined that IR 83381-B-B-137-1 excelled in grain yield when supplied with 100% RDF. Mukamuhirwa *et al.* (2018) assessed Rwandan rice cultivars, with Jyambere achieving the highest yield (17.4 g/plant). Javeed *et al.* (2018) obtained the highest grain and straw yields with a phosphorus-potassium treatment of 35:15 kg/ha of P and K, while the nitrogen treatment at 60 kg N/ha produced the best results. Kumar *et al.* (2018) found that the highest level of fertilizer application (150: 75: 37.5 kg NPK/ha) led to superior grain and straw yield compared to other fertility levels. Paramasivan *et al.* (2018) reported that applying 200:75:75 kg NPK/ha led to highest growth attributes and yield attributes of rice crop. Vanija *et al.* (2019) in mechanized rice cultivation found that the highest yields occurred with 90:30:60 kg NPK/ha, exceeding the standard check (100:60:40). Masni and Walsi (2019) observed that increasing fertility levels didn't significantly increase yield for the red rice variety MRM 16, with the highest yield under NPK (120:70:80) compared to lower NPK treatment. Under upland rainfed agroecosystem, growing of Swarna Shreya (22.1 kg/ha/day) and advanced breeding line IR 84899-B-179-13-1-1-1(20.9 kg/ha/day) along with application of 180 kg N/ha (Kumar *et al.* 2020) and IR 88964-11-2-2-4 (33.9 kg/ha/day) along with 150% RDN (Kumar *et al.* 2019) under lowland transplanted condition can be an ideal approach to achieve higher crop productivity. Also, residue retention of rice can enhance the soil carbon quality and health in the Indo-Gangetic plains of India (Mahala *et al.* 2023). A field experiment conducted at Pantnagar (Table 1) reported that the rice varieties IET-27263 and NDR-359 can achieve increased yields by employing 150% of the180:90:60 kg NPK/ha RDF (Bahuguna *et al.* 2023).

Effect of NPK and genotypes on nutrient uptake and nutrient use efficiency of rice

Metwally *et al.* (2011) studied rice variety "H1" and found that increasing N levels up to 200 kg N/ha improved N use efficiency, but further increases in N levels decreased efficiency. In a greenhouse experiment with 7 lowland rice genotypes (CNAi 8859, CNAi 8860, CNAi 8870, CNAi 8879, CNAi 8880, CNAi 8886 and CNAi 8885) by Fageria (2014), it was reported that P use efficiency (control and 200 mg P/kg) showed significantly difference among genotypes. Kumar *et al.* (2015) reported that the in-rice variety RCM 11 application of 100% RDF along with 5 tonnes of rice straw/ha resulted in a substantial increase in the uptake of NPK by both the grain and straw surpassing the effectiveness of alternative nutrient management methods. Murthy *et al.* (2015) conducted a field experiment with the objective to optimize fertilizer doses in rice variety MTU 1010 with different fertility levels and reported that N uptake (149 kg/ha) was highest with NPK @210: 60: 40 kg/ha, P (32.62 kg/ha) with 120: 105: 40 kg/ha and K (198 kg/ha) with 120: 60: 70 kg/ha. Nanda *et al.* (2017) found that in rice variety HUBR 10-9, NPK levels up to 100% RDF in rice significantly increased NPK content and removal by grain and straw. Kumar *et al.* (2017) examined the rice cultivar HUR 917 and observed that the application of 100% RDF resulted in substantial enhancements in NPK removal compared to different level of fertilizer application. Kumar *et al.* (2018) in a field experiment with fertility levels of 120: 60: 30 kg NPK/ha in rice variety PAC-837 recorded highest nutrient uptake which was found to be at par with variety DRRH-3. Nath *et al.* (2018) reported that the highest nutrient uptake, including 145.35: 25.60: 179.5 kg NPK/ha, was observed with 180: 90: 90 kg NPK/ha, level of fertilizer application significantly higher than the lowest fertility level (120: 60: 60 kg NPK/ha). Paramasivan *et*

Table 1 Effect of fertilizer levels and genotypes on yield attributing characters, yield and economics of rice

Treatment	Panicles no./m²	Panicle length (cm)	Grain weight (g/ panicle)	1000-grain weight	Yield (t/ha)			Harvest index	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
					Grain	Straw	Total				
Fertilizer level											
Control	188	21.2	1.93	25.3	2.56	2.94	5.50	0.48	44858	18252	0.68
100% RDF	232	23.8	2.06	25.2	4.15	4.57	8.72	0.48	81811	49197	1.50
150% RDF	248	25.4	2.26	25.6	4.73	5.18	9.91	0.48	93064	57458	1.61
SEm±	2	0.27	0.02	0.14	0.17	0.19	0.32	0.05	2842	2661	0.03
LSD (P=0.05)	10	1.08	0.12	NS	0.44	0.58	1.01	NS	8526	7985	0.09
Genotype											
IET-27263	238	23.6	2.20	27.4	4.30	4.67	8.97	0.48	80458	48850	1.54
IET-26418	207	22.6	1.99	23.8	3.53	3.93	7.46	0.47	67068	35460	1.12
IET-26420	217	23.0	1.82	23.2	3.42	3.67	7.09	0.48	65056	33448	1.05
NDR-359	221	23.7	2.11	24.5	4.22	4.66	8.88	0.48	78256	46648	1.47
PD-19	231	24.3	2.06	27.3	3.82	4.34	8.16	0.47	74836	43228	1.36
PD-26	219	23.2	2.18	25.5	3.61	4.12	7.73	0.47	73801	42193	1.33
SEm±	2	0.21	0.005	0.4	0.06	0.09	0.21	0.05	337	326	0.01
LSD (P=0.05)	6	0.70	0.080	1.2	0.23	0.25	0.65	NS	1012	1003	0.03
CV (%)	14.3	6.9	6.58	3.9	8.3	11.3	12.63	4.6			

Source: Bahuguna *et al.* (2023)

al. (2018) reported that applying 200:75:75 kg NPK/ha results in highest NPK uptake (171.9, 28.6 and 185.2 kg/ha). Samartha *et al.* (2019) observed that NPK uptake in grain was significantly higher under 100% NPK compared to 50% and 75% NPK treatments. Verma *et al.* (2023) reported that highest N, P and K content in grain and straw were found with inorganic nutrient management practices in Shahsarang 1 variety of rice in Eastern Himalayan region.

Mondal *et al.* (2013) demonstrated that application of 125: 62.5: 62.5 NPK kg/ha in hybrid rice paid the highest gross return of 87,970 ₹/ha and net return of 59,695 ₹/ha. Pramanik and Bera (2013) observed that higher gross return (83,562 ₹/ha and 88,138 ₹/ha), net return (52,898 ₹/ha and 57,474 ₹/ha), net return per rupee (₹2.73 and ₹2.87) and B:C ratio (1.73 and 1.87) was obtained with 150 kg N/ha and decreased at higher N doses (200 kg/ha) in hybrid rice 25-P-25. Kumar *et al.* (2017) examined the rice cultivar HUR 917 and observed that the application of 100% RDF resulted in higher gross (82356 ₹/ha) and net returns (48009 ₹/ha) compared to different level of fertilizer application. Srivastava *et al.* (2014) in a field experiment found that combination of 100% RDF with 30 kg N/ha through vermicomposting gave highest net returns (59,804 ₹/ha). With the objective to optimize the fertilizer doses of major nutrients, Murthy *et al.* (2015) conducted a field experiment and found that highest gross returns (58339 ₹/ha), net returns (30398 ₹/ha) were recorded with application of NPK @210-60-40 kg/ha in variety MTU 1010 while NPK @180-90-60 kg/ha appears to be optimum dose. Kumar *et al.* (2017) found that among four rice varieties, PAC-837 exhibited the highest grain and straw yields, along with superior net returns (4,002.28 ₹/ha) and a favorable B:C ratio (1.24) and recommended as the most profitable choice. Nanda *et al.* (2017) found that in rice variety HUBR 10-9, cost of cultivation (36206.50 ₹/ha), gross return (94828.26 ₹/ha) and net return (58621.75 ₹/ha) were obtained maximum with 100% RDF. Paramasivan *et al.* (2018) reported that applying 200:75:75 kg NPK/ha results in highest net returns (52,600 ₹/ha) and B:C ratio (1.65). Verma *et al.* (2018) indicated that utilizing integrated nutrient management (INM) involving 75% RDF and 25% organic inputs like FYM, along with microbial inoculants, could enhance both productivity and profitability of lowland rice in the Eastern Himalayas. Under upland rainfed agroecosystem of Bihar, growing of Swarna Shreya (23000 ₹/ha) and advanced breeding line IR 84899-B-179-13-1-1-1(21900 ₹/ha) along with application of 180 kg N/ha (Kumar *et al.* 2020) and IR 83383-B-B-129-4 (38181 ₹/ha) along with 150% RDN (Kumar *et al.* 2019) under lowland transplanted condition of Bihar can be an ideal approach to achieve higher monetary returns (Table 2). Bahuguna *et al.* (2023) at Pantnagar reported that genotype IET-27263 exhibits significantly higher net return (48850 ₹/ha) and B: C ratio (1.54) compared to other genotypes (Table 1). Sahu *et al.* (2023) observed that rice variety Sabour Ardhjal with 75% chemical fertilizer+25% FYM, achieved better system productivity and profitability

Table 2 Effect of nitrogen levels on yields and economics of rice genotypes (Pooled data of 2 years)

Treatment	Grain yield (t/ ha)	Straw yield (t/ ha)	Biological yield (t/ha)	Crop productivity (kg/ha/day)	Dry matter efficiency (kg/ha/day)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio	Economic efficiency (₹/ha/day)
Nitrogen level									
Control	2.61	5.19	7.80	21.9	65.4	48202	12886	1.36	108
50% RDN	3.42	6.34	9.76	27.9	79.7	62504	22725	1.57	185
100% RDN	4.56	8.10	12.66	36.2	100.7	82892	42482	2.05	336
150% RDN	5.19	9.41	14.60	40.6	114.3	94563	52260	2.24	409
LSD (P=0.05)	0.11	0.22	0.30	0.9	2.7	1915	1915	0.05	16
Rice genotypes									
IR 83383–B–B–129–4	4.27	7.61	11.88	31.6	88.0	77633	38181	1.94	281
IR 83387–B–B–27–4	4.09	7.50	11.59	33.1	94.0	74629	35177	1.87	283
IR 88867–9–1–1–4	3.89	7.20	11.09	32.9	93.8	71040	31588	1.79	266
IR 88964–24–2–1–4	3.97	7.40	11.36	33.2	95.2	72572	33120	1.81	275
IR 88964–11–2–2–4	4.07	7.45	11.53	33.9	95.9	74322	34870	1.86	288
IR 88966–39–1–4–4	3.77	6.99	10.75	30.1	86.0	68892	29440	1.73	234
Rajendra Sweta	3.96	7.24	11.20	28.7	81.2	72308	32856	1.82	238
Rajendra Bhagwati	3.54	6.69	10.23	29.7	85.9	64925	25473	1.63	213
LSD (P=0.05)	0.15	0.31	0.43	1.3	3.8	2708	2708	0.07	22

Source: Kumar *et al.* (2019)

of rice-wheat cropping system may be promoted for wider adaptability at the farmers' fields of eastern Indo-Gangetic Plains of Bihar.

Numerous findings have elucidated the profound impact of fertilizers on rice cultivation, demonstrating the significance of nutrient management for distinct genotypes to enhance yield and sustainability. Findings indicate that moderate fertilizer application, customized to specific genotypes and environmental conditions, often leads to optimal growth, improved nutrient uptake, and enhanced yield. However, excessive fertilizer application can result in diminishing returns, environmental degradation, and economic inefficiency due to nutrient imbalances and soil degradation Furthermore, the genotype-specific responses to fertilizers, advocating for precision agriculture approaches to maximize productivity while reducing environmental footprints. Notably, the adaptation of innovative techniques, such as site-specific nutrient management (SSNM) as demonstrated by Dobermann *et al.* (2002), has exhibited promising results in optimizing fertilizer application, thereby ensuring sustainable rice production and minimizing environmental risks. However, the wide-scale adoption of such strategies faces challenges related to farmer awareness, accessibility to resources, and socio-economic factors. The complexity of genotype-environment interactions necessitates continuous research to develop robust genotype-specific fertilizer management strategies to bolster rice production sustainably. Therefore, while acknowledging the pivotal role of fertilizers in augmenting rice productivity, it is important to adopt a holistic and context-specific approach, integrating genotype characteristics, environmental conditions, and efficient nutrient management practices to achieve sustainable intensification and ensure food security in rice cultivation.

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