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Effect of STCR based NPK application on yield, quality of soybean and available nutrient status in a Vertisol of Madhya Pradesh

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Abstract

A field experiment was conducted at the Research Field of the Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh during *kharif* season of 2015-16 to evaluate the effect of NPK fertilization on productivity, seed quality of soybean and available nutrient status in post-harvest soil under STCR approach The study consisted of five treatments of five treatments of NPK doses comprised of control, GRD and three yield targets (25, 30 and 35 q ha^{-1}), which were replicated four times in a Randomized Block Design. Results indicated that the maximum seed (15.96 q ha^{-1}) and stover (26.72 q ha^{-1}) yields of soybean were recorded under higher yield target of 35 q ha^{-1}, which marked a 94.4% increase over the control and greatly exceeded the general recommended dose (GRD). Quality parameters of soybean seed such as oil (19.65%), protein (41.63%) and starch (59.43%) contents consistently increased with upward NPK doses, although variations between high-target yield treatments were statistically equal. Post-harvest soil analysis showed that STCR-based NPK fertilization greatly increased available nitrogen, phosphorus and potassium compared to the control and GRD, effectively preventing nutrient mining. The study concludes that the STCR approach enhances soybean productivity, improves seed quality and maintains soil fertility, especially at higher yield targets. This STCR approach offers a sustainable and scientifically sound substitute for blanket fertilizer recommendations for improving farm profitability and soil health in the Vertisol of Central India.

Keywords: Available soil nutrients, NPK fertilization, productivity, STCR approach, seed quality, soybean

Introduction

Soybean (*Glycine max* L. Merrill), a member of the family *Leguminaceae*, stands as one of the most significant oilseed crops in the world. It is highly valued for its nutritional density, containing 40-42% high quality protein and 20-22% oil, alongside essential amino acids, vitamins and minerals. Furthermore, bioactive substances such as isoflavones found in soybeans, which improve human health by reducing the risk of cardiovascular diseases (heart disease) and certain types of cancer (Barik and Chandel, 2001; Kumar *et al*., 2007) [4]. In recent years, global soybean production and trade have been influenced by climate variability and technological advancements in crop management (FAO, 2024). In India, soybean is a cornerstone of the oilseed economy, primarily cultivated during the *kharif* season. Recent statistics indicate that soybean was grown on about 10.88 million hectares with a production of 10.44 million tonnes, although their average productivity remains relatively low. However, a significant gap persists between potential yields and current average productivity (Hegde, 2025) [10]. Madhya Pradesh, widely recognized as the “Soybean Bowl of India,” dominates the country’s soybean acreage and production. Despite this supremacy, productivity in the state is hampered by several reasons, most notably declining fertilizer use efficiency and uneven fertilizer application (Korav *et al*., 2024; Hegde, 2025) [14, 10].

As the global population is projected to reach 11.2 billion by 2100, the pressure on limited land resources to ensure food security is intensifying. Soil serves as the primary medium for plant growth, supplying the essential nutrients, moisture and providing mechanical support needed for crop development. Consequently, maintaining soil fertility is paramount to sustaining agricultural productivity and ensuring global food security.

Fertilizers are essential for increasing crop yields and restoring nutrients that crops have lost. However, modern nutrient management emphasizes balanced fertilization, which entails providing all essential nutrients in adequate and appropriate proportions to meet crop requirements (Khan *et al*., 2024) [12]. Application of fertilizers without the proper knowledge of nutrient status of soil, causes an adverse effect on both soil and crop health. So, balanced nutrients application is one of the most important factors for efficient crop growth and increasing the quality of the product. Traditionally, the key primary macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) have been the focus of agricultural nutrient management. Soybean exhibits distinct physiological responses to nutrient management, especially N, P and K fertilization. Nitrogen is essential to promote vegetative growth and protein synthesis while, phosphorus plays a vital role in successful nodulation, root growth and energy transfer processes, all of which affect seed quality and yield. Potassium is equally important for enzyme activity, water regulation, and tolerance to abiotic stress. Therefore, in order to prevent continuous soil fertility depletion or "mining," sustainable crop production necessitates replenishment of nutrients lost after crop harvest (Abishek *et al*., 2022) [1].

Fertilizers are among the most important and expensive inputs in agriculture and their efficient use is crucial to increase farm profitability and preserve environmental sustainability (Kimetu *et al*., 2004) [13]. In India, fertilizer recommendations are frequently derived from broad state-level guidelines. However, crop nutrient requirements vary widely depending on soil fertility status and agro-climatic conditions. Consequently, blanket or general fertilizer recommendations could result in either insufficient or excessive fertilization, which would impair profitability, reduce productivity, and pollute the environment. Without a thorough understanding of the nutrient condition of the soil, excessive or imbalanced fertilizer application can potentially degrade soil quality and have a detrimental impact on crop performance. Hence, balanced nutrient management based on scientific soil analysis has become essential for increasing crop productivity and maintaining soil health.

Conventional fertilizer recommendations generally classify soils into low, medium and high fertility groups based on available nutrient levels. However, there are frequently significant differences in nutrient availability within these classes, which reduces the efficacy of broad recommendations. In this context, the Soil Test Crop Response (STCR) approach offers a more accurate and scientific way to calculate fertilizer. The STCR approach has replaced blanket fertilizer recommendations with site-specific nutrient management (SSNM)**.** By taking into account the baseline soil fertility status, crop nutrient requirements, and nutrient contribution from soil, fertilizers and organic sources, it uses fertilizer prescription equations to propose nutrient doses for reaching particular yield targets (Abishek *et al*., 2022) [1]. The concept of targeted yield was pioneered by Troug (1960) [16] and later modified by Ramamoorthy *et al*. (1967) [17] to fit Indian conditions. This approach establishes a quantitative relationship between soil test values, fertilizer doses and crop yield, enabling balanced fertilization and efficient nutrient utilization. Prescription-based fertilizer recommendations, which are generated using STCR equations, allow farmers to apply the precise amounts of nutrients needed to achieve a predetermined yield target under specific agro-climatic conditions. By assuring effective fertilizer application and addressing soil nutrient imbalances, such soil test-based nutrient management not only improves crop productivity but also increases the benefit-cost ratio. Recent studies have shown that STCR based fertilizer recommendations can boost crop yields by 15-58% by addressing site-specific nutrient deficiencies and improving nutrient uptake efficiency (Hegde, 2025) [10].

Despite the recognized importance of balanced fertilization and targeted nutrient management, systematic and location-specific studies are needed to develop appropriate fertilizer recommendations for specific agro-ecosystems. In Madhya Pradesh, improper nutrient management often results in reduced crop productivity and long-term problems such as nutrient mining and decline in soil microbial diversity (Khan *et al*., 2024; Hegde, 2025) [12, 10]. Therefore, optimizing soybean production systems requires an understanding of the link between nutrients delivered by soil and those added through fertilizers. In light of the above facts, the present investigation was undertaken to evaluate the effect of STCR based NPK application on productivity and nutrient status of post-harvest soil of soybean. By providing a comprehensive assessment of nutrient dynamics under targeted yield-based fertilization, the study seeks to identify NPK management strategies that are both economically efficient and environmentally sustainable for the agro-ecosystems of Madhya Pradesh.

Materials and Methods

A field experiment was conducted at the Research Field of the Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh during the *kharif* season of 2015-16. The investigation aimed to evaluate the effect of NPK application on yield, quality of soybean and available nutrients status of post-harvest soil. The soil of the experimental field was a medium black (Vertisol), exhibiting characteristic shrink-swell behavior. Taxonomically, it belongs to the Kheri series of the fine, montmorillonitic, hyperthermic family of *Typic Haplusterts*. Prior to the experiment, composite soil surface samples from 0-15 cm depths were collected by using a screw auger, then processed and analyzed soil physico-chemical properties and available N, P and K status by standard analytical procedures. The soil was clayey in texture with pH (7.58), electrical conductivity (0.19 dS m^{-1}), organic carbon (5.17 g kg^{-1}), available N (200.71 kg ha^{-1}), available P (15.61 kg ha^{-1}) and available K (367.15 kg ha^{-1}). The study consisted of five treatments of NPK levels comprised of T_1: Control (No NPK); T_2: General Recommended Dose-GRD (20:60:20 kg N, P_2O_5 and K_2O ha^{-1}); T_3: Targeted Yield-T.Y. 25 q ha^{-1} (33:66:17 kg N, P_2O_5 and K_2O ha^{-1}); T_4: T.Y. 30 q ha^{-1} (59:92:36 kg N, P_2O_5 and K_2O ha^{-1}) and T_5: T.Y. 35 q ha^{-1} (85:118:56 kg N, P_2O_5 and K_2O ha^{-1}), which were replicated four times in a Randomized Block Design. Based on the initial soil test values and desired target yields (25, 30 and 35 q ha^{-1}) of soybean, the NPK doses were calculated by using site-specific fertilizer adjustment equations for soybean developed for the region.

Fertilizer Adjustment Equations for Soybean

$FN = 5.19\,T - 0.48\,SN$, $FP_2O_5 = 5.20\,T - 4.10\,SP$ and $FK_2O = 3.90\,T - 0.22\,SK$

[Where, FN, FP_2O_5 and FK_2O = Fertilizer N, P and K (kg ha^{-1}); T = Desired yield target (q ha^{-1}), SN, SP and SK = Available soil N, P and K (kg ha^{-1})]

The seed of soybean (cv. JS 97-52) was sown at row spacing of 40 cm in 10 × 5 m^2 plots on 29 June, 2015. Fertilizers doses were applied as per the established fertilizer adjustment equations for desired targeted yield of soybean crop. The fertilizers dose for soybean as per treatment was applied as nitrogen, phosphorus and potassium per plot as basal doses. Standard agronomic practices were adopted for this region, maintained uniformly across treatments to minimize experimental variation. The crop was harvested at physiological maturity on 23 October, 2015.

The observations for seed and stover yields of soybean were recorded after threshing manually and expressed in quintals per hectare (q ha^{-1}). Quality parameters such as protein, oil and starch contents in soybean seed were analyzed after harvest of crop. For quality assessment, representative seed samples from each treatment and replication were oven-dried, pulverized, passed through 2 mm sieve and used for further quality analyses. The protein content in soybean seed was estimated using the percent total nitrogen value multiplied by crude protein factor 6.25. For protein content, the total nitrogen content in soybean seed was estimated by micro-Kjeldahl method as suggested by AOAC (1995) [3]. Oil content in seed was estimated by Soxhlet's apparatus as per method described by AOAC (1995) [3]. The starch content in soybean seed was analyzed by using Anthrone reagent method as per described by Hedge and Hofreiter (1962) [9].

For available nutrients status assessment, post-harvest soil sample of each plot of the experimental field was collected from 0-15 cm soil depth, then processed and were used for analyses of available N, P and K status. The available N content in post-harvest soil was determined by the alkaline potassium permanganate method as described by Subbiah and Asija (1956) [18]. Available P content in soil was estimated by extraction procedure using 0.5 M $NaHCO_3$ as described by Olsen's *et al.* (1954) [19] and colour developed by ascorbic acid as per method described by Watanabe and Olsen's (1965) [20] while, available K content in soil was extracted with neutral normal ammonium acetate and estimated by using Flame photometer as described by Jackson (1973) [11]. The data of each parameter was tabulated and subjected to Analysis of Variance (ANOVA) for a RBD (Gomez and Gomez, 1984) [8]. The significant differences among treatment means were identified using the Critical Difference (CD) test at a 5% level of probability.

Results and Discussion

Seed and Stover Yields

The data pertaining to seed and stover yields of soybean as influenced by STCR based NPK application are presented in Table 1 and Fig. 1. Data further clearly indicated a significant increase in both seed and stover yields of soybean with increasing doses of NPK nutrients. The results revealed that the maximum seed yield (15.96 q ha^{-1}) was recorded under treatment T_5 consisting of 85:118:56 kg N, P_2O_5 and K_2O ha^{-1} (T.Y. 35 q ha^{-1}), which was significantly superior to the rest of the treatments but at par with treatment T_4 having T.Y. 30 q ha^{-1} (14.60 q ha^{-1}). However, the minimum seed yield (8.21 q ha^{-1}) was recorded in treatment T_1 (control). Similarly, maximum stover yield (26.72 q ha^{-1}) was recorded in treatment T_5 (T.Y. 35 q ha^{-1}), which was statistically significant compared to control (18.15 q ha^{-1}) and GRD (22.34 q ha^{-1}). The substantial increase in seed and stover yields with higher NPK levels may be attributed to improved nutrient availability and uptake under STCR-based fertilization. Balanced application of NPK enhances vegetative growth, photosynthetic efficiency, and translocation of assimilates from source to sink, thereby improving yield attributes and final productivity. Nitrogen promotes vegetative growth and protein synthesis, phosphorus enhances root development and reproductive growth, while potassium regulates enzyme activity and improves stress tolerance, collectively contributing to higher biomass and yield. Similarly, Dhillon *et al*. (2023) [6] observed that STCR-based nutrient management not only improves yield but also maintains soil health by preventing over-application or under-application of specific macronutrients. Furthermore, the superior performance of targeted yield treatments (T_4 and T_5) clearly indicates the effectiveness of STCR approach in supplying nutrients in accordance with crop demand, resulting in better nutrient use efficiency and higher productivity. Similar findings are in close agreement with Kumar *et al*. (2023) [15] who reported that STCR approach significantly improved soybean yield compared to GRD and control. Patel and Meena (2021) [21] stated that optimized NPK levels enhance the "source" capacity, leading to a higher number of pods/ grains and overall seed yield.

Oil, Protein and Starch Contents

The data on quality parameters of soybean seed *viz*., oil, protein and starch contents as influenced significantly by different doses of NPK application under STCR-based targeted yield approach (Table 2). Results revealed that oil content in soybean seed ranged from 18.27 to 19.65%, with the highest content (19.65%) recorded with higher doses of NPK ha^{-1} having T.Y. of 35 q ha^{-1} (T_5). However, none of the treatments differed significantly among themselves except control (18.27%). Similarly, highest protein content (41.63%) was obtained in treatment T_5, which was significantly superior to control (39.25%) but at par with remaining treatments. Starch content in seed followed a similar upward trend with precision nutrient application. The highest starch content (59.43%) was registered under treatment T_5 (85:118:56 kg N, P_2O_5 and K_2O ha^{-1}) and lowest in control (55.91%). However, starch content showed non-significant differences among treatments. The gradual increase in starch content under higher nutrients levels may be due to enhanced photosynthetic activity and efficient translocation of assimilates towards developing seeds. Further, improved nutrient availability under higher NPK levels promotes carbohydrate synthesis and storage, thereby increasing starch content. The enhancement of oil, protein and starch contents with higher levels of NPK may be attributed to improved nutrient availability and uptake, which enhanced metabolic activities and biosynthesis of storage compounds in soybean seeds. The improvement of seed quality parameters through balanced fertilizers under targeted nutrient application is a reflection of improved metabolic activities within the plant. Similarly, Bhatt *et al*. (2021) [5] reported that balanced fertilization under STCR regimes optimizes the source-sink relationship, ensuring that the biochemical quality of the produce is not compromised by nutrient stress. Furthermore, Mishra and Nayak (2022)

[22] noted that when N, P and K are applied in higher, balanced quantities (T_5), the plant's physiological efficiency improves, resulting in higher contents of primary metabolites like starch and lipids. These findings are in conformity with Singh *et al*. (2021) [5] who reported that balanced and site-specific nutrient management improves seed quality attributes such as oil and protein content, though the magnitude of change is often limited. Similar results obtained by Abishek *et al*. (2022) [1] and Hegde (2025) [10] observed that STCR-based NPK application enhances nutrient uptake and metabolic efficiency, resulting in improved biochemical composition of soybean seeds.

Available Soil N, P and K Status

The data indicates that the application of NPK doses under STCR approach significantly enhanced the available N, P and K contents in post-harvest soil (Table 3). The results revealed a marked improvement in available soil nutrient status with increasing levels of NPK application. The maximum content of available N (177.87 kg ha^{-1}) was recorded under treatment T_5 consisting of 85:118:56 kg N, P_2O_5 and K_2O ha^{-1} (T.Y. 35 q ha^{-1}), which was significantly superior to the rest of the treatments except treatment T_4 (166.39 kg ha^{-1}), which was statistically at par. However, the minimum content of available N (126.17 kg ha^{-1}) was obtained under control treatment having without applied NPK. The increase in available N might be due to higher NPK application along with enhanced biological nitrogen fixation (BNF) in soybean, which contributes to residual N in soil. Improved root growth and microbial activity under balanced fertilization also play a key role in increasing soil N availability. Available P content in post-harvest soil followed a similar trend, with maximum content (16.73 kg ha-1) recorded in treatment T_5 (T.Y. 35 q ha^{-1}), which was significantly superior to the rest of the treatments, while minimum (10.37 kg ha^{-1}) in control. The targeted yield treatments showed a significant buildup of soil P compared to the control (T_1) and GRD (T_2). The increase in available P with higher NPK levels may be attributed to direct addition of phosphatic fertilizers and reduced fixation due to better soil chemical environment. Balanced fertilization also enhances root proliferation and secretion of organic acids, which help in mobilizing native P into available forms. Furthermore, the higher P application in treatment T_5 likely saturated the P-fixation sites in the soil, thereby increasing the amount of P remaining in the available pool. Similarly, the highest status of available K (325.88 kg ha^{-1}) in post-harvest soil was recorded in treatment T_5 consisting of higher doses of NPK (T.Y. 35 q ha^{-1}), which was significantly superior to all other treatments but at par with treatment T_4 (303.65 kg ha^{-1}) having T.Y. of 30 q ha^{-1}. The increase in available potassium with higher doses of NPK might be due to direct application of potassic fertilizers and improved nutrient cycling through better crop growth and residue return. Furthermore, the higher K levels in treatment T_5 indicate that the application of 56 kg K_2O ha^{-1} was sufficient to offset crop uptake and increase exchangeable K. Similarly, Rao and Janardhan (2022) [23] observed that targeted yield regimes prevent the "mining" of soil K, which is a common problem in blanket fertilization (GRD) where K application is often low.

The significantly higher availability of N, P and K in treatments T_4 (T.Y. 30 q ha^{-1}) and T_5 (T.Y. 35 q ha^{-1}) may be attributed to the higher external application of these nutrients via the STCR equations. As highlighted by Prasad *et al*. (2023) [24], site-specific nutrient management ensures that the soil solution remains saturated enough to meet crop demand while leaving behind residual fertility for the succeeding crop. Furthermore, the progressive increase in available N, P and K with increasing fertility levels clearly indicates the effectiveness of STCR-based fertilizer application in maintaining and improving soil fertility status. The results demonstrate that nutrient application based on targeted yield not only meets crop demand but also leaves sufficient residual nutrients in soil, thereby sustaining soil health. Moreover, the synergistic interaction among N, P and K also contributes to better nutrient retention and reduced leaching losses, thereby improving overall soil fertility (Khan *et al*., 2024) [12]. Recent findings by Meena *et al.* (2024) suggest that using targeted yield equations leads to a significant improvement in the nutrient use efficiency and ensures the long-term fertility of the soil matrix. The results are also strongly supported by the findings of Singh *et al*. (2021) [5] and Abishek *et al.* (2022) [1]. The results of present study are also strongly supported by the findings of Similarly, Hegde (2025) [10] who observed that targeted yield-based fertilization enhances nutrient use efficiency and increases residual soil fertility by minimizing nutrient losses.

Conclusion

The study concludes that NPK application based on STCR approach greatly improves yield, seed quality of soybean and residual soil nutrients status over conventional recommendations. The maximum seed (15.96 q ha^{-1}) and straw (26.72 q ha^{-1}) yields were recorded with the application of 85:118:56 kg N, P_2O_2 and K_2O ha^{-1} (T.Y. of 35 q ha^{-1}). This approach also improved seed quality, particularly oil (19.65%), protein (41.63%) and starch (59.43%) contents, while maintaining a superior available N, K and K status in post-harvest soil. Consequently, targeted yield-based fertilization proves to be a scientifically sound approach for achieving higher profitability and long-term soil fertility.

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Table 1: Effect of STCR based NPK application on seed and stover yields of soybean

Treatments	Seed yield (q ha^{-1})	Stover yield (q ha^{-1})
T_1: Control	8.21	18.15
T_2: GRD (20:60:20 kg $N:P_2O_5:K_2O$ ha^{-1})	11.57	22.34
T_3: T. Y. 25 q ha^{-1} (33:66:17 kg $N:P_2O_5:K_2O$ ha^{-1})	13.15	24.21
T_4: T. Y. 30 q ha^{-1} (59:92:36 kg $N:P_2O_5:K_2O$ ha^{-1})	14.60	25.57
T_5: T. Y. 35 q ha^{-1} (85:118:56 kg $N:P_2O_5:K_2O$ ha^{-1})	15.96	26.72
SE m ±	0.61	1.05
CD $_{(p = 0.05)}$	1.87	3.21

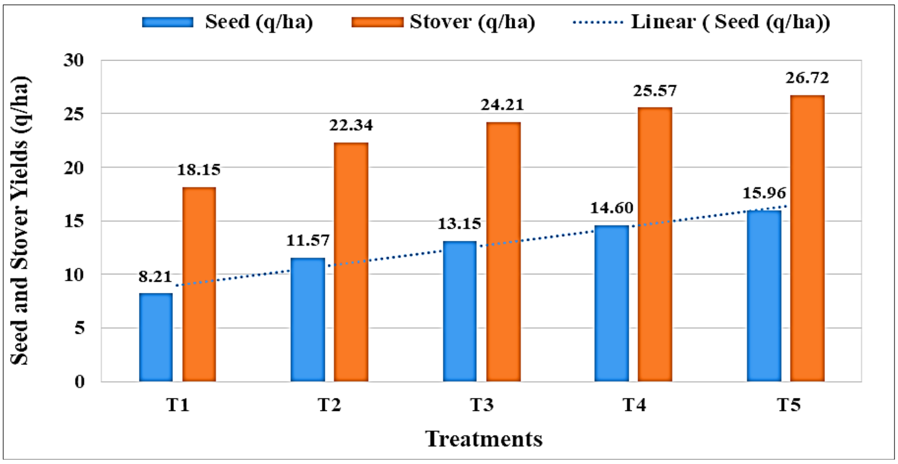

Fig 1: Seed and stover yields of soybean as influenced by STCR based NPK application

Table 2: Effect of STCR based NPK application on oil, protein and starch contents in soybean seed

Treatments	Oil content (%)	Protein content (%)	Starch content (%)
T_1: Control (No fertilizer)	18.27	39.25	55.91
T_2: GRD (20:60:20 kg $N:P_2O_5:K_2O$ ha^{-1})	18.65	40.31	56.83
T_3: T. Y. 25 q ha^{-1} (33:66:17 kg $N:P_2O_5:K_2O$ ha^{-1})	19.11	40.75	57.65
T_4: T. Y. 30 q ha^{-1} (59:92:36 kg $N:P_2O_5:K_2O$ ha^{-1})	19.43	41.19	58.57
T_5: T. Y. 35 q ha^{-1} (85:118:56 kg $N:P_2O_5:K_2O$ ha^{-1})	19.65	41.63	59.43
SE m ±	0.39	0.77	1.05
CD $_{(p = 0.05)}$	1.21	2.36	3.25

Table 3: Effect of STCR based NPK application on available N, P and K status in post-harvest soil

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1: Control (No fertilizer)	126.17	10.37	267.21
T_2: GRD (20:60:20 kg $N:P_2O_5:K_2O$ ha^{-1})	138.93	12.65	278.47
T_3: T. Y. 25 q ha^{-1} (33:66:17 kg $N:P_2O_5:K_2O$ ha^{-1})	141.15	13.83	288.93
T_4: T. Y. 30 q ha^{-1} (59:92:36 kg $N:P_2O_5:K_2O$ ha^{-1})	166.39	15.15	303.65
T_5: T. Y. 35 q ha^{-1} (85:118:56 kg $N:P_2O_5:K_2O$ ha^{-1})	177.87	16.73	325.88
SE m ±	3.99	0.29	8.27
CD $_{(p = 0.05)}$	12.30	0.90	25.47

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