***Original Research Article***

**Optimizing Wheat Production and Resource Use Efficiency under Varying Tillage and Residue Management Systems**

### **Abstract**

A field investigation was carried out during two consecutive rabi seasons (2019–20 and 2020–21) at the Research Farm, College of Agriculture, RVSKVV, Gwalior, Madhya Pradesh, to evaluate the effect of different tillage and residue management practices on growth, yield performance, and resource use efficiency in wheat (*Triticum aestivum L.*). The experiment was laid out in a randomized complete block design (RCBD) comprising six treatment combinations involving conventional and zero tillage with and without residue retention on flat and raised beds. The results indicated that conventional tillage on raised beds with residue retention (CT-RB+R) significantly improved plant growth parameters, yield attributes, grain yield, and economic returns compared to other treatments. Pooled data analysis revealed that CT-RB+R recorded the highest grain yield (5050 kg ha⁻¹), which was statistically at par with conventional tillage on flat beds with residue (CT-FB+R: 4758 kg ha⁻¹), and significantly superior to zero tillage without residue (ZT–R: 4225 kg ha⁻¹). The maximum benefit-cost ratio (2.57) was achieved under ZT+R. The findings underscore the potential of integrated tillage and residue management practices, particularly CT-RB+R, for enhancing wheat productivity and economic viability under the semi-arid agro-ecological conditions of central India.

*Keywords:* Tillage, Raised bed, Conservation, Nutrient, Economics, Wheat

### **Introduction**

Wheat (*Triticum aestivum* L.) is a globally significant cereal crop and a cornerstone of food security, particularly in India where it occupies a substantial portion of the rabi season cropping area. It provides a major source of calories and protein for millions and plays a vital role in sustaining rural livelihoods and the national economy. With increasing population pressure and the rising demand for food, enhancing wheat productivity in a sustainable manner has become imperative. India has seen significant growth in wheat production over the last 75 years, especially in the years following the Green Revolution. Nevertheless, the agricultural industry continues to face obstacles in spite of these advancements, such as plateauing yield potential, declining irrigation water supplies, and current farm-level yield disparities. Besides, due to climate change and the depletion of natural resources, agriculture is currently facing previously unparalleled challenges (Chawla and Balasaheb, 2023).

Despite significant advances in crop breeding and agronomic technologies, wheat yields in many parts of India have plateaued in recent years. One of the key contributing factors to this stagnation is the continuous adoption of conventional tillage practices. Intensive tillage disturbs the soil structure, accelerates organic matter decomposition, and contributes to soil compaction, erosion, and nutrient imbalances. Over time, these practices have resulted in soil degradation, reduced water retention capacity, and diminished biological activity, which ultimately limit crop growth and productivity (Li *et al*., 2008; Mosaddeghi *et al.*, 2009).

In response to these challenges, conservation agriculture practices—particularly those involving reduced or zero tillage and the incorporation or retention of crop residues—have gained attention for their potential to improve soil health, enhance input use efficiency, and sustain crop productivity. Residue retention on the soil surface moderates soil temperature, improves moisture conservation, suppresses weed emergence, and enhances the activity of beneficial soil microorganisms. Moreover, residues act as a slow-release nutrient source, contributing to soil fertility and biological processes (Meena *et al.*, 2015).

The synergy between appropriate tillage systems and residue management plays a pivotal role in optimizing soil-plant-environment interactions. Raised bed planting, for instance, has been shown to improve water infiltration, root growth, and aeration, particularly under resource-constrained environments. When combined with residue retention, such systems can potentially offer a resilient and productive approach to wheat cultivation under semi-arid and sub-humid agro-ecological conditions (Kumar *et al.*, 2020).

In India, especially in the Indo-Gangetic Plains and adjoining regions like Madhya Pradesh, the dominance of cereal-cereal cropping systems has resulted in excessive residue burning and overexploitation of natural resources. While rice-wheat systems have received considerable research attention, limited studies have evaluated the integrated effects of tillage and residue management in wheat monoculture or diversified cropping sequences.

Therefore, the present investigation was undertaken to assess the impact of different tillage and residue management practices on the growth, yield attributes, productivity, and economic returns of wheat.

### **Materials and Methods**

The experimental site was located at 23°10′ N latitude and 79°54′ E longitude with an elevation of 411.98 meters above mean sea level, situated in the northern agro-climatic zone of Madhya Pradesh. The field experiment was carried out during *Rabi* seasons of 2019–20 and 2020–21 at the Research Farm, College of Agriculture, R.V.S.K.V.V., Gwalior. The experimental site possessed a uniform land topography with adequate surface drainage, while internal drainage was categorized as medium. The meteorological data recorded during the crop growth period (November to April) included moderate to low rainfall with mean monthly relative humidity ranging between 43 to 96% during 2019-20 and 43 to 94% during 2020-21. Temperature ranged from a minimum of 4.9°C in February to a maximum of 36.1°C in March–April during the experimentation. The site experiences a typical semi-arid climate. The experimental soil was well-drained sandy clay loam in texture in the upper 30 cm profile. Initial soil fertility status indicated low available nitrogen (187 kg/ha), low in organic carbon (0.49%), and medium in available phosphorus (12.4 kg/ha) and potassium (224 kg/ha).

The field experiment was conducted using a randomized complete block design (RCBD**)** with six treatments and three replications. The six tillage and residue management treatments were: **T1**: Conventional tillage-flat bed without residue incorporation (CT-FB–R), **T2**: Zero tillage without residue incorporation (ZT–R), **T3**: Conventional tillage-raised bed without residue incorporation (CT-RB–R), **T4**: Conventional tillage-flat bed with residue incorporation (CT-FB+R), **T5**: Zero tillage with residue incorporation (ZT+R) and **T6**: Conventional tillage-raised bed with residue incorporation (CT-RB+R).

The conventional tillage treatments involved primary tillage with a mouldboard plough followed by secondary tillage using a cultivator and leveling with a plank to achieve a fine seedbed. In zero tillage treatments, no preparatory tillage was conducted, and wheat seeds were directly sown using a zero-till drill. Raised beds were prepared manually forming furrows of 30 cm and a top width of 180 cm. In residue retained treatments, crop residues from the previous season were incorporated or uniformly spread over the soil surface as per treatment requirement. In residue removal plots, all residues were cleared before sowing.

Wheat variety *RV4106*, suitable for the region, was used for sowing at a row spacing of 22.5 cm and a seed rate of 100 kg/ha. The seeds were treated with Captan 2.0 g/kg seed and Chlorpyriphos 4 ml/kg seed for protection against fungal diseases and termites, respectively. Recommended dose of fertilizers (120:60:40 kg N:P₂O₅:K₂O per ha) was applied. Half of the nitrogen and full doses of phosphorus and potassium were applied as basal, while the remaining nitrogen was top-dressed at the first irrigation. Two Irrigations during the first and three irrigations during the second year were provided uniformly at critical stages and weed control was done using pendimethalin @ 1.0 kg a.i./ha as pre-emergence followed by one hand weeding at 30 DAS.

At crop maturity, observations on morphological and yield parameters such as plant height, number of effective tillers/m², number of grains per spike, 1000-grain weight, grain yield, straw yield, biological yield, and harvest index were recorded from the net plot area. Economic analysis was carried out by calculating gross returns, net returns, and benefit-cost ratio based on prevailing input and output prices.

Soil samples were collected from 0–15 cm depth before sowing and after harvest from each replication using a composite sampling method. Samples were air-dried, ground, and passed through a 2 mm sieve for physicochemical analysis. The data recorded from field observations and laboratory analyses were statistically analyzed using the standard procedures as per Gomez and Gomez (1984). The treatment means were compared using the least significant difference (LSD) test at 5% level of significance. Pooled analysis over the two years was carried out to evaluate the consistency of treatment effects across seasons.

**Result and discussion**

### ***Effect of tillage practices on growth parameters***

The results exhibited a significant influence of tillage and residue management treatments on growth parameters such as plant height, number of tillers per plant, dry matter accumulation, and phenological development (days to 50% spike emergence and maturity). The data (Table 1) revealed that practicing conventional tillage on raised beds with residue retention (CTRB+R) significantly enhanced plant growth, as evidenced by greater plant height, higher tiller production, and maximum dry matter accumulation across all observation stages. This treatment also led to the earliest flowering and physiological maturity.

On a pooled basis, the treatment CTRB+R recorded the tallest plants with plant heights of 30.1, 50.5, and 100.9 cm at 30, 60, and 90 days after sowing (DAS), respectively, which were significantly superior to all other treatments. However, at 60 DAS, the treatment remained statistically at par with conventional tillage flat bed with residue (CT+R) and conventional tillage raised bed without residue (CT-RB-R) during 2020. A similar non-significant difference was observed at 90 DAS between CT-RB+R and CT+R in 2019, and with CT-RB-R in 2020. The zero tillage without residue (ZT-R) treatment consistently resulted in significantly shorter plants at all stages during both years and on pooled basis too.

The enhanced plant height observed in the bed-tilled and residue-retained plots could be attributed to improved soil moisture availability, moderated temperature, and better aeration—factors that promote vigorous shoot elongation and physiological activity. These findings are supported by Svubure *et al.* (2010) and Sharma *et al.* (2011), who reported improved nutrient mineralization and availability under tilled conditions, leading to better plant growth and development.

Similarly, analysis of tiller production revealed that CTRB+R recorded the maximum number of tillers per plant at all stages. This treatment produced 5.19, 10.5, and 10.5 tillers per plant at 30, 60, and 90 DAS, respectively, which was 48.57%, 50.0%, and 50.0% higher than the control (CT-FB-R). Treatments CT-RB-R and CT-FB+R also recorded significantly more tillers compared to the zero tillage plots, particularly ZT-R, which showed the lowest tiller counts at all stages during both years and on pooled basis. At 90 DAS, ZT-R recorded a 33.0% and 32.7% reduction in tiller count compared to the control in 2019 and 2020, respectively, indicating its negative impact on tiller development due to poor soil physical conditions.

Dry matter accumulation (DMA) was also highest under CT-RB+R, with pooled values of 15.08 g, 58.8 g, and 349 g per plant at 30, 60, and 90 DAS, respectively. This treatment was followed by CT-RB-R and CT-FB+R, which recorded statistically comparable DMA values at 90 DAS. In contrast, ZT-R produced the lowest dry matter at all stages. At 90 DAS, CT-RB+R resulted in a 50.0% and 50.2% increase in DMA over ZT-R during 2019 and 2020, respectively. These improvements are likely the result of better root proliferation, higher nutrient uptake, and continuous moisture supply under raised bed and residue-retained systems. Similar findings were reported by Kumar *et al.* (2020), who observed greater biomass production due to improved moisture supply under wide raised beds with residue retention compared to zero tillage.

Furthermore, the phenological observations revealed significant differences among the tillage and residue management treatments. The minimum number of days to 50% spike emergence (77.1 days pooled) and physiological maturity (127.9 days pooled) was observed under Conventional Tillage Raised Bed with Residue (CT-RB+R), indicating accelerated crop development due to favorable soil and microclimatic conditions. These improvements can be attributed to better soil moisture retention, enhanced microbial activity, and optimal nutrient availability, all of which facilitated early reproductive transition and physiological completion.

In contrast, Zero Tillage without Residue (ZT-R) and Zero Tillage with Residue (ZT+R) recorded delayed spike emergence and maturity, with ZT-R taking 79.9 days to spike emergence and 130.6 days to maturity. These delays may be a consequence of suboptimal seedbed conditions, reduced soil aeration, and slower nutrient mineralization, which hinder plant metabolic processes and extend the vegetative and reproductive phases.

These findings clearly highlight the advantage of conventional tillage, particularly when combined with residue retention and raised bed planting, in accelerating wheat crop development. This system not only ensures early vigor and better biomass accumulation but also shortens the growth cycle, potentially enhancing cropping intensity and resource use efficiency in sequential cropping systems. However, our findings are in contrast with those of Chhokar *et al.* (2018) who reported that wheat sown with happy seeder or turbo seeder under full residue retention showed improved early growth, enhanced tiller formation, and faster phenological development compared to conventional methods.

Table 1. Effect of tillage practices with residue management on pooled data of both the years at growth parameters of wheat (pooled)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatment** | **Plant height (cm)**  | **Number of tillers/plant** | **Days to 50% spike emergence** | **Days to maturity** |
| 30 DAS | 60 DAS | 90 DAS | 30 DAS | 60 DAS | 90 DAS |
| **Conventional tillage Flat bed without residue** | 24.2 | 40.9 | 84.3 | 4.2 | 8.8 | 8.8 | 79.9 | 129.9 |
| **Zero tillage without residue** | 19.9 | 34.8 | 79.2 | 3.5 | 7.0 | 7.0 | 79.9 | 130.6 |
| **Conventional tillage Raised bed without residue** | 28.2 | 47.8 | 95.7 | 4.5 | 9.1 | 9.1 | 78.0 | 129.3 |
| **Conventional tillage Flat bed with****residue** | 26.3 | 44.9 | 90.7 | 4.9 | 9.7 | 9.7 | 77.5 | 128.6 |
| **Zero tillage with residue** | 23.2 | 37.7 | 82.5 | 4.6 | 9.4 | 9.4 | 78.5 | 129.4 |
| **Conventional tillage Raised bed with residue** | 30.1 | 50.5 | 100.9 | 5.2 | 10.5 | 10.5 | 77.1 | 127.9 |
| **SEm±** | 0.46 | 0.77 | 1.60 | 0.07 | 0.13 | 0.13 | 0.43 | 0.99 |
| **CD (0.05)** | 1.33 | 2.24 | 4.61 | 0.19 | 0.37 | 0.37 | 1.24 | 2.86 |



|  |
| --- |
|  Fig1: Effect of tillage practices and residue application on Dry Matter accumulation at 30, 60 and 90 DAS |

### ***Effect of tillage practices on LAI, CGR and RGR***

It was determined from the variance analysis results of LAI, CGR, and RGR that tillage treatments with and without residue retention significantly influenced these parameters at all growth stages during the two years of study. The average of the two-year data revealed that leaf area index at 30, 60, and 90 DAS was significantly highest (1.67, 3.68, and 5.74, respectively) under conventionally tilled raised bed plots with residues retained on the surface (CT-RB+R). However, this treatment was found at par with conventional tillage raised bed without residue (CT-RB-R) and conventional tillage flat bed with residue (CT-FB+R) during both 2019 and 2020.  Fig. 2(a): Effect of tillage practices and residue application on Leaf Area Index (LAI) at 30, 60 and 90 DAS

Likewise, on a pooled basis, crop growth rate (CGR) was recorded significantly highest (1.46 and 9.67 g/m²/day, respectively) with CTRB+R during both 30–60 and 60–90 DAS compared to other tillage treatments. The increase in CGR under this treatment was 19.67% and 20.0% over the control and 50.5% and 49.9% over zero tillage without residue (ZT-R), respectively, indicating a positive effect of tillage and residue retention on dry matter accumulation and overall growth performance.

With respect to relative growth rate (RGR), treatments showed a different trend at all growth stages during the two years and on pooled basis. The treatment of conventional tillage flat bed with residue (CT-FB+R) remained superior over the zero tillage treatments and recorded significantly highest RGR values (0.0456 and 0.0328 g/g/day, respectively) at 30–60 and 60–90 DAS. However, statistically similar values were recorded under conventional tillage raised bed with residue (CT-RB+R), conventional tillage raised bed without residue (CT-RB-R), and conventional tillage flat bed without residue (CT-FB-R).

This might be due to better conservation of rainwater, improved soil aeration, and moderated soil temperature under tillage with residue retention, leading to enhanced root proliferation and sustained plant growth. In addition, residues retained on the surface contributed to a slower and continuous release of nutrients into the soil, ensuring their availability throughout the crop growth stages. However, the conventional and conservation tillage treatments did not significantly influence RGR at 60–90 DAS during both 2019 and 2020, indicating a convergence of relative growth efficiency in the later growth stages across treatments. Similar findings were reported by Sangakkara *et al.* (2004) and Scopel *et al.* (2004), who observed a notable impact on plant-available water with an increased amount of surface residue.

|  |  |
| --- | --- |
|  |  |
|  Fig 2(b): Effect of tillage practices and residue application on crop growth rate (CGR) at 30, 60 and 90 DAS  | Fig 2(c): Effect of tillage practices and residue application on relative growth rate (RGR) at 30, 60 and 90 DAS  |

### ***Effect of tillage practices on nutrient contents and their total uptake***

The results of analysis of variance for N, P and K concentrations in grain and straw demonstrated a significant and positive effect of tillage systems and residue retention on both nutrient concentrations and their total uptake by wheat. Based on pooled data, conventional tillage on raised beds with residue retention (CT-RB+R) produced the highest concentrations of N, P and K in grain (1.81 %, 0.34 % and 0.50 %, respectively) and in straw (0.48 %, 0.62 % and 1.27 %, respectively), significantly exceeding all other treatments. The treatment CT-RB+R was statistically at par with conventional tillage on flat beds with residue (CT+R) for grain K concentration, indicating that residue retention under either tillage system similarly enhances K availability.

The elevated nutrient concentrations under CT-RB+R may be ascribed to enhanced mineralization of soil organic matter and improved microbial activity due to combined effects of soil disturbance and surface mulch. Residue retention moderates soil temperature and moisture, thereby sustaining microbial processes that release nutrients gradually throughout crop growth (Usman *et al*., 2014).

With respect to total nutrient uptake, CTRB+R again led to the highest values: N uptake of 91.5 kg ha⁻¹, P uptake of 60.8 kg ha⁻¹, and K uptake of 119.7 kg ha⁻¹ (pooled). These uptakes were 61 %, 83 % and 76 % greater than those under zero tillage without residue (ZT–R), and 42.3 %, 38.8 % and 39.8 % greater than the conventional flat bed without residue control (CTF), respectively. Such marked improvements underscore the synergistic benefit of combining raised‐bed tillage with residue retention for maximizing nutrient mobilization and crop acquisition.

|  |  |
| --- | --- |
|  |  |
| Fig 3(a): Effect of tillage practices & residue application on N, P and K content in grain (%) | Fig 3(b): Effect of tillage practices & residue application on N, P and K content in straw (%) |



Fig 3(c): Effect of tillage practices and residue application on Total Nutrient Uptake (kg/ha)

### ***Effect of tillage practices on yield attributes and yields***

The tillage practices exhibited a significant influence on all yield-attributing characters and yields of wheat (Table 2). Conventional tillage on raised beds with residue incorporation (CT-RB+R) consistently recorded the highest number of effective tillers per m², number of spikes per m², grains per spike, 1000-grain weight, and final grain yield in both years and pooled analysis. The grain, straw, and biological yields were significantly highest under CT-RB+R, with recorded values of 5017 kg/ha (grain), 6920 kg/ha (straw), and 11,937 kg/ha (biological yield) in 2019, and 5084 kg/ha (grain), 7179 kg/ha (straw), and 12,263 kg/ha (biological yield) in 2020. These yields were consistently higher than those observed under zero tillage and other conventional tillage treatments. In fact, CT-RB+R exhibited a 31.3% and 31.2% increase in grain yield over ZT-R in 2019 and 2020, respectively. It also outperformed the control (CT-FB—R) by 19.5% in the pooled data.

Interestingly, CT flatbed with residue (CT-FB+R) produced similar yields to CT-RB+R for most yield components, further confirming that residue retention is beneficial under conventional tillage systems. These findings are in line with those reported by Panday *et al.* (2008) and Singh *et al*. (2010) however in contrast with the findings of Sahrawat *et al.* (2010), who found higher number of effective tillers/m2  under zero tillage resulted in in comparison to conventionally sown wheat.

Table 2. Effect of tillage practices with residue management on pooled data of both the years at yield attributes and yield of wheat (pooled)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Effective tillers/** **m²** | **Number of spikes/** **m²** | **Number of grains/ spike** | **Grain weight/spike (g)** | **1000 grain weight (g)** | **GrainYield** **(kg/ha)** | **Straw yield (kg/ha)** | **Biological Yield (kg/ha)** | **HI** |
| **Conventional tillage Flat bed without residue** | 263 | 69.4 | 40.5 | 1.76 | 39.98 | 4225 | 5385 | 9609 | 0.44 |
| **Zero tillage without residue** | 210 | 65.5 | 38.7 | 1.76 | 38.74 | 3849 | 4044 | 7894 | 0.46 |
| **Conventional tillage Raised bed without residue** | 273 | 78.1 | 46.8 | 1.78 | 41.29 | 4377 | 5641 | 10018 | 0.44 |
| **Conventional tillage Flat bed with****residue** | 289 | 81.6 | 49.5 | 1.78 | 41.95 | 4758 | 6554 | 11312 | 0.42 |
| **Zero tillage with residue** | 282 | 74.4 | 42.9 | 1.78 | 40.58 | 4439 | 5724 | 10163 | 0.44 |
| **Conventional tillage Raised bed with residue** | 315 | 84.1 | 52.6 | 1.79 | 42.62 | 5050 | 7050 | 12100 | 0.42 |
| **SEm±** | 1.6 | 0.92 | 0.63 | 0.002 | 0.504 | 48.8 | 112.1 | 139.7 | 0.003 |
| **CD (0.05)** | 4.5 | 2.67 | 1.83 | 0.004 | 1.455 | 140.8 | 323.7 | 403.4 | 0.009 |

***Effect of tillage practices on economics***

The assessment of economic returns (Table 3) across the years 2019, 2020, and pooled data indicated that CT-RB+R (Conventional tillage raised bed with residue retention) achieved the highest gross and net returns, amounting to ₹97,472 and ₹68,283 (pooled) per hectare, respectively. This treatment was followed by CT flatbed with residue (CT-FB+R) and CT raised bed without residue (CT-RB-R), both of which demonstrated strong performance, generating higher gross returns across the respective years compared to other treatments.

On the other hand, the lowest gross returns were observed under the ZT-R (Zero tillage without residue) treatment, which yielded ₹74,291 per hectare, significantly lower than the other treatments.

Based on the pooled analysis, CT-RB+R resulted in a 31.2 and 42.6% increase in gross and net returns compared to ZT-R and a 19.5 and 36.6% improvement over CT-FB—R (control). Significantly highest Benefit-Cost (B:C) ratio across different tillage and residue management treatments was recorded under ZT+R, with values of 2.55, 2.59, and 2.57 in 2019, 2020, and the pooled analysis, respectively. This was followed by CT-RB+R, which recorded B:C ratios of 2.32, 2.36, and 2.34, and CT flatbed with residue (CT-FB+R) with B:C ratios of 2.12, 2.17, and 2.15 across the same periods. These findings highlight the economic advantage of raised-bed tillage combined with residue retention, demonstrating its potential to enhance farm income and contribute to long-term sustainability.

**Table 3.** Effect of tillage practices with residue management on pooled data of both the years at economics of wheat (pooled)

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **Gross returns (Rs/ha)** | **Net returns (Rs/ha)** | **Benefit Cost Ratio** |
| **Conventional tillage Flat bed without residue** | 81538 | 49948 | 1.58 |
| **Zero tillage without residue** | 74291 | 47901 | 1.82 |
| **Conventional tillage Raised bed without residue** | 84471 | 52882 | 1.67 |
| **Conventional tillage Flat bed with****residue** | 91827 | 62638 | 2.15 |
| **Zero tillage with residue** | 85663 | 61674 | 2.57 |
| **Conventional tillage Raised bed with residue** | 97472 | 68283 | 2.34 |
| **SEm±** | 941.1 | 941.1 | 0.032 |
| **CD (0.05)** | 2718.1 | 2718.1 | 0.092 |

### ***Conclusion***

Based on the results obtained from a two-year study, it is concluded that wheat responded positively in terms of growth, yield, nutrient uptake, and economic returns under the system of conventional tillage on raised beds with residue retention. This tillage and residue management practice proved to be the most advantageous under the sandy clay loam soils of the Gird region (Zone VIII), Madhya Pradesh (Gwalior).

From the experiment, zero-tillage without residue consistently performed the poorest across all parameters. Hence, its adoption is not advisable unless supplemented with frequent and adequate inputs—such as chemical or organic fertilizers—to compensate for the limited root growth and restricted nutrient access typically associated with this practice. Therefore, it is recommended that farmers in this region adopt the raised bed + residue incorporation system as a sustainable management practice to enhance wheat productivity and profitability.

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**Disclaimer (Artificial intelligence)**

We hereby declare that no generative AI technologies such as Large Language Models, etc have been used during the writing or editing of manuscripts.

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